Risk, Systems and Decisions

Igor Linkov
Jesse M. Keenan
Benjamin D. Trump *Editors*

COVID-19: Systemic Risk and Resilience

Springer

Risk, Systems and Decisions

Health, environment, security, energy, technology are problem areas where man-made and natural systems face increasing demands, giving rise to concerns which touch on a range of firms, industries and government agencies. Although a body of powerful background theory about risk, decision, and systems has been generated over the last several decades, the exploitation of this theory in the service of tackling these systemic problems presents a substantial intellectual challenge. This book series includes works dealing with integrated design and solutions for social, technological, environmental, and economic goals. It features research and innovation in cross-disciplinary and transdisciplinary methods of decision analysis, systems analysis, risk assessment, risk management, risk communication, policy analysis, economic analysis, engineering, and the social sciences. The series explores topics at the intersection of the professional and scholarly communities of risk analysis, systems engineering, and decision analysis. Contributions include methodological developments that are well-suited to application for decision makers and managers.

More information about this series at http://www.springer.com/series/13439

Igor Linkov · Jesse M. Keenan ·
Benjamin D. Trump
Editors

COVID-19: Systemic Risk and Resilience

Springer

Editors
Igor Linkov
Engineer Research and Development Center
US Army Corps of Engineers
Concord, MA, USA

Jesse M. Keenan
Tulane University
New Orleans, LA, USA

Benjamin D. Trump
Engineer Research and Development Center
US Army Corps of Engineers
Concord, MA, USA

ISSN 2626-6717 ISSN 2626-6725 (electronic)
Risk, Systems and Decisions
ISBN 978-3-030-71586-1 ISBN 978-3-030-71587-8 (eBook)
https://doi.org/10.1007/978-3-030-71587-8

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Contents

Chapter 1
Multi-Disciplinary Perspectives on Systemic Risk and Resilience in the Time of COVID-19

Benjamin D. Trump, Jesse M. Keenan, and Igor Linkov

Abstract The novel coronavirus (COVID-19) has had sweeping consequences upon global societies, public health, and economies. It stubbornly persisted and spread throughout 2020, despite a range of policy and social response strategies from frontline global public health institutions and countries alike. Consequences of such policy responses will persist for years and even decades, reshaping both government practices and social behaviors. The responses and impacts from COVID will shape and influence the global order for collective responses to everything from public health issues to climate change. However, questions abound regarding how the public and private sectors might best anticipate similarly situated systemic risks and position society to better recover from and adapt to the "new normal" associated with rapid global change.

Keywords Systemic risk · COVID-19 supply chains · Supply-chain management · Supra-systems · Resilience during COVID-19

1.1 Covid-19

The COVID-19 crisis is both unique and far more complex in its acute and disruptive capacity than prior international crises and emergencies, such as the Global Financial Crisis (2007–2009) or, from a global perspective, any war since World War II. Specifically, its disruptive potential is not due to underlying failures of markets or hotly contested battlefields and military objectives. Instead, it is a public health crisis that has inspired governments to gradually decrease and even shut

B. D. Trump · I. Linkov (✉)
U.S. Army Corps of Engineers, ERDC, Concord, MA 01742, USA
e-mail: Igor.Linkov@usace.army.mil

J. M. Keenan
Tulane University, New Orleans, LA 70118, USA

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_1

down major sectors of economic and social life in order to prevent and control the rate of infection so as to manage an infected population at levels within peak public health capacity. Beginning as an exogenous shock via rapid global contagion, COVID has had far-reaching effects as national and international policies to limit and control infection have cascaded to affect other interconnected systems that have triggered a multitude of crises—ranging from energy and fossil fuels; to unemployment and housing; to supply chain management and continuity; and, to even the very nature of international relations and multilateral coordination. Further, bottom-up responses by individuals and communities strengthen the feedback loops that characterize our highly interconnected world, creating a multitude of common (s) problems as individuals prioritize, to differing and occasionally combative degrees, personal liberty, protection of personal and household health, improvement of one's financial position, and various other drivers of opinion and action.

Likewise, several factors make the impacts of COVID-19 so immediate and sweeping: (i) the sensitivity associated with the extreme levels of interconnection between various societal systems; and (ii) the exposures associated with—increasingly efficient yet brittle—global systems designed to eliminate redundancy in order to maximize a largely unregulated return-on-investment among global markets and investors. In this sense, the globalization of transnational economies has come at the cost of internal domestic capacity that offers redundancy in times of crisis. As such, societal and economic systems are increasingly interdependent upon one another, generating feedback loops where a disruption to certain systems (e.g., industrial and manufacturing activity in the People's Republic of China) can trigger indirect yet considerable losses or perturbations to seemingly unrelated systems (e.g., international fossil fuel markets and energy policy between the Russian Federation, Saudi Arabia, and the United States). At the same time, a drive for hyper-efficient markets helps reduce waste or resource/product redundancies in a manner that allows a nation to focus upon a limited subset of goods, services, or raw materials as its primary mode of economic competition. Yet, more fundamentally, it also leaves a country vulnerable to shortages in various products or materials in the event of supply chainsupply chain disruptions such as those generated by COVID-19.

As countries navigate through and beyond the pandemic crisis, significant discussion is raised on how to recover and adapt economic and social systems in the disruptive aftermath of COVID-19. Generally, these discussions fall into two general lines of inquiry: (i) how do we preserve, recover, and improve local economies from a sudden and unpredictable demand shock (e.g., in the form of a mandated reduction of economic activity); and, (ii) how do we adapt socioeconomic systems to prevent and/or mitigate future disruptions, effectively preserving normatively positive national and local economic systems?

The answers to the inquiries require policymakers to address the fragility of hyper-efficient supply chain systems and their lack of bottom-up resilience capacities. At present, many policy solutions are possible to address these challenges.

Some will lead to robust economic recoveries and improved resilience within local economies, while others will seek options that do not address the underlying systemic vulnerabilities that have contributed to the multitude of economic and social crises at present. Most troubling is that it is neither obvious nor easy to discern which path specific strategies may be most effective. However, one fact has become abundantly clear given a year of experience in pandemic response—it is critically important to prioritize and imbed the philosophy and practice of resilience within critical systems that underpin major facets of modern life. To fully understand the nature of resilience, one must first understand the emergent and dynamic parameters of systemic risk.

1.2 Systemic Risk

Immediately after the declaration of a global pandemic in early 2020, the rush to halt the spread of disease soon spiraled into a multitude of tangential crises, including crises associated with human health and health care delivery systems; supply chain management and continuity; labor market participation; debt, equity and currency market performance and stability; consumer and commercial demand; and housing. In the earliest months of the pandemic, many governments addressed one or more of these issues through dedicated responses, including fiscal stimulus and asset purchasing to preserve jobs, backstop liquidity, and stabilize housing markets, among other policies and investments. However, for the most part, these efforts generally prioritized the preservation and stability of existing societal and economic systems. These efforts were not strategically designed to drive recovery or to support expanded models of economic growth.

Many economic markets and corresponding globalized systems of production and distribution were designed for maximum value extraction through efficient and lean operations. To add complexity, such systems are often further shaped by: (i) the increasing digitalization of national and local economies among networks of producers, distributors and consumers; and (ii) national responses to financial crises in recent decades, much of which favored top-down interventions to protect and preserve market-critical firms in various sectors (i.e., too big to fail).

At present, a lack of income and commercial spending is weighing down economies, making it difficult for individuals and families to pay a variety of debts (e.g., housing, educational, commercial) or to fully participate in the commercial exchange of goods and services. The net losses associated with the ossification of socioeconomic life are nonlinear and exacerbated by the very same systems that COVID-19 disrupted, contributing to rapid and substantial economic losses to household wealth, local businesses, and local and national tax revenue. In prior financial crises, often defined by valuation bubbles within one asset class or another, systemic risk manifested in the freezing of credit impacting the supply of good and services. However, with COVID-19, there are dual constraints on supply and demand. Therefore, supra-systems associated with entire sectors and national economies are facing multiple shocks and stresses from both system and sub-systemic constraints on the multi-directional flow of capital. In prior financial crises, the goal was to limit the contagion of perceived and actual losses to sub-systemic levels (Fig. 1.1).

Recovery-minded strategies in a post-COVID-19 world must include a tandem of top-down and bottom-up strategies that preserve global trade and exchange while also providing national and local communities with a measure of slack to accommodate future disruptions to these or other systems. Top-down, countries must identify core critical functions that must be preserved and maintained regardless of the type of disruption at hand. Medical supplies, critical consumer goods, digital systems and interconnectivity, and other services and products must either (i) have locally-produced options, or (ii) prevent the simplification and interconnection of supply chains between small numbers of countries in a manner that a disruption to a single supply line can generate shortages or losses to other countries. For firms requiring assistance, it is essential for governments to ensure that core industries that support national critical functions are able to preserve their institutional memory and roster of skilled professionals and capital equipment. This is especially true for critical industries that currently face furloughs, layoffs, or unpaid leave as production down is downscaled. As the industry's activity improves, those core industries with intact labor pools will be better positioned to fuel economic growth and drive innovation. In other cases, certain industrial capacity will need to be re-domesticated to build an adaptive capacity for future crises.

1.3 Resilience

Bottom-up, policymakers must consider options to preserve and recover local economies that have been disrupted or halted as COVID-19 progresses. This includes preventing liquidity traps at the sub-systemic level, where sudden losses in consumer spending reduce business and wage income, and thereby taxes to local and national governments. However, these investments must also prepare, if necessary, for the transformation of firms and sectors to adapt to changing circumstances shaping the supply and demand of their respective markets. In this regard, this strategy is not only about maintaining market share but also about expanding to new markets and opportunities. As the COVID-19 crisis abates, ensuring that households are able to meet core needs and participate in their local economy is essential to placing communities on a trajectory towards recovery. This may include continued local assistance, as well as a shift in policy that disincentives the accumulation of large and/or predatory debts that deprive households of slack and choice in the presence of future crises.

Practically, what does a resilience-driven focus mean? It is important to note that a resilience approach to a pandemic response does not mean returning to the 2019 status quo. This is simply not possible in terms of social learning and the reordering of private goods and modified consumer preferences. As of this publication, over a year of sociopolitical and socioeconomic experience has been incorporated into societal functions and behaviors. In more immediate terms, interventions and societal shifts that were intended to be temporary have now become ingrained within culture (e.g., a substantial shift towards online shopping). In many cases, stakeholders and practitioners of resilience will need to decipher which areas or practices warrant the investment towards recovery and adaptation and which are less necessary in the immediate term.

In many cases, some of the bottom-up or top-down innovations and work-arounds to troubleshoot the unique difficulties of pandemic life may yield improvements over prior ways of thinking—leading to operations that are innately defined by resilience and sustainability. This is particularly critical in the age of climate change and global change, as countries seek to mold recovery in a manner that is catalytic for a transition to a net-zero global economy. But, resilience, sustainability, and adaptation also interact to address systemic and sub-systemic risks within critical asset classes and the financial economy writ large.

Instead, resilience for pandemic policy implies a capacity for recovery that benefits from social learning but also benefits from the designed adaptive capacity of systems to face future shocks and stresses—and to transform, if necessary. Rather than building back critical infrastructure, economies, or societal practices to reflect a pre-COVID-19 state, many can and should use this opportunity to invest scarce resources in prioritizing critical functions and capacities. For example, development toward advanced telecommunications will yield greater connectivity and faster Internet for portions of the population that have limited to no such service. By extension, improvements in this space will lead to outsized benefits related to primary and secondary education, telework, telemedicine, and various other critical sectors of society. However, internalizing resilience requires a more comprehensive focus on plausible and desirable future states that reflects a re-prioritization of critical resources and capacities .

In the near-term, there are four possible futures (see Fig. 1.2): (i) one with neither mitigation nor recovery (top-left); (ii) one with both mitigation and recovery (bottom-right); (iii) one with harm mitigation but slow recovery (bottom-left); and (iv) one with extensive loss but also with rapid recovery (top-right). The present selection of any is highly normative, with corresponding political and economic consequences.

Many governments have already signaled a desire to take decisive action. Some are blunting economic losses through targeted or blanket investments, while others are considering policies to utilize the disruption as a means to reform industries or economic sectors. Recovery-minded approaches will best position national governments and local communities to improve their capacities to weather future crises. In theory, systems with inherent redundancies or: "resilience-by-design" are far more sustainable than those of extreme efficiency alone. Of course, if a country overspecializes in the specific resilience of one sector or another, it may undermine is competitiveness within the global economy. Therefore, the challenge is to

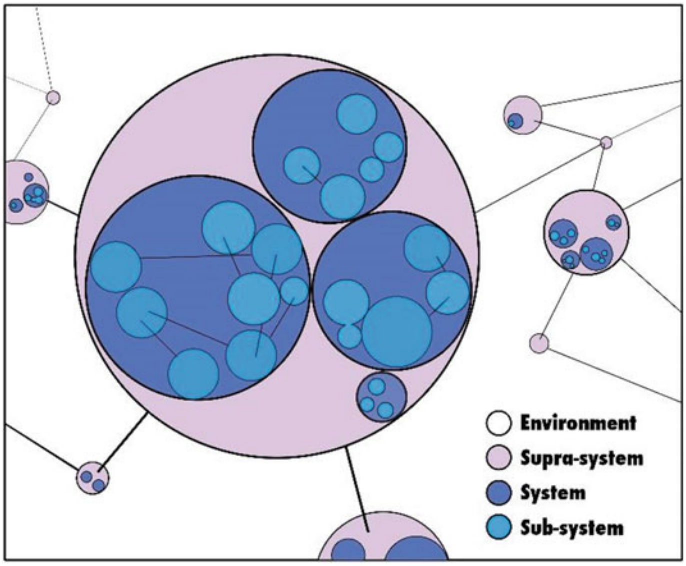

Fig. 1.1 Example of efficient supra-system design with complex interconnected systems and sub-systems that generate feedback loop behaviors

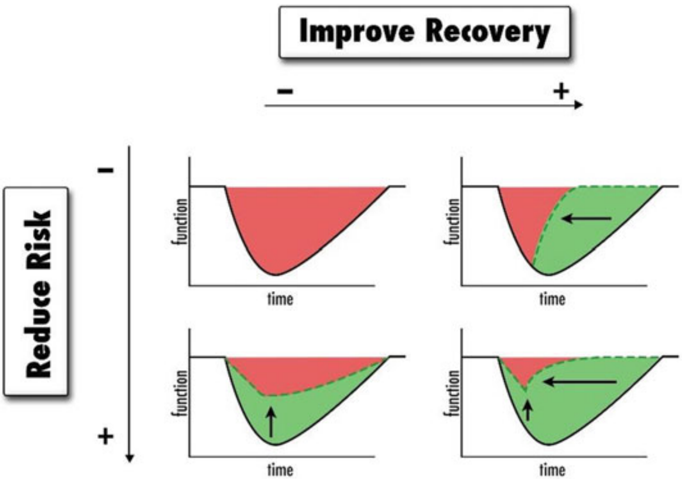

Fig. 1.2 Different Policy Permutations Post-COVID-19

balance domestic interests for sector-specific resilience with efficiency demands of a global economy (Trump et al. 2020).

Each country, firm, and community will need to decide for itself the areas where investment in resilience is both worthwhile and normatively positive.

Two proactive and concurrent resilience strategies can be implemented by both industry and government. Resilience-by-design can be a baseline methodology to make systems resilient without undue burden on efficiency and company bottom lines; and resilience-by-intervention implies readiness for point failures of entire supply networks through stockpiling and other government policies, ensuring that critical corporate and societal needs continue to be met post-disruption. Both strategies require resilience analytics to drive implementation design and efficiency/resilience tradeoffs. Many systems or activities may already have requisite resilience-by-design and are well on the path towards recovery in a normatively beneficial fashion. Others, however, may be fundamentally brittle, and comprised of many rate-limiting steps or single points of failure that leave them vulnerable to ongoing disruption and considerable loss. As such, disruptions to one critical sector (e.g., secondary education) may be driven by cascading disruptions to others (e.g., infrastructure, communications, public health, poverty, etc.). When people limit work to homeschool children, the economic consequences are significant—particularly as it relates to the disproportionate impact that such activities have on women in the workforce. Without appropriate interventions to each potential cause of disruption, we leave open the possibility that future disruption and cascading loss may occur yet again. Therefore, a whole systems approach is necessary to balance not only efficiency and redundancy, but also a variety of values that society deems paramount to shaping sustainable and distributionally equitable pathways of future recovery and development.

1.4 Contributions of This Book

This book provides a variety of disciplinary perspectives that, together, shape a comprehensive understanding of COVID-19′s impacts, as well as pathways for recovery, resilience, and adaptation within the context of a rapidly changing world. From history to economics and from technologically-driven social organization to public health, this book advances theoretical and empirical knowledge through the lens of understanding systemic risk and resilience. Here, resilience is understood in its various categorical forms, including descriptive and normative manifestations.

The book begins with a core theoretical empirical contribution that positions the observed systemic nature of COVID-19 impacts. Thereafter, various frameworks are presented that seek to articulate management and policy approaches that are drawn from the resilience scholarship and practice. From this immediate perspective, subsequent chapters take a step back to provide a macro-economic and deep historical perspective on the manifestations of risk and corresponding capacities of economies and societies to cope and to adapt.

From here, a group of chapter seeks to synthesize this interaction between market economies and societies as a means to explore resilience in the built environment. This includes an exploration of the cross-learning between urban resilience, climate change, and COVID-19. These chapters provide a critical examination of the extent to which current resilience performance has benefited our current responses, as well as the extent to which our current responses stress test our current understanding of resilience. This group of chapters focused on the built environment is capped with an exhaustive economic evaluation of the extent to which cities express resilience in the performance of their urban economies and housing markets.

The next group of chapters focuses on the intelligence and communications systems that are necessary for everything from compliant social behavior to the optimization of resource allocations in the delivery of healthcare resources. These chapters highlight the critical role of social learning and the capacity of self-organization that drive the execution of resilience interventions. To highlight this capacity for self-organization, the final chapter in this group provides a novel perspective on the emergence of mutual aid networks that are driven by diffuse and highly distributed social networks. This chapter highlights that social infrastructure has its own set of emergent behaviors which speak to the resilience of both its individual members and the sustainable capacity of the collective organizations to drive resilience and social welfare outcomes.

Social welfare outcomes are the concern of the following group of chapters, which position multiple scales of specific and general resilience performance. In particular, these chapters offer compelling arguments for an intermedia meso-scale approach to community resilience consistent with regional interventions. They argue that top-down fiscal stimulus and ground-up community aid are important, but often overlook dynamic regional processes that offer an opportunity for scaled systemic engagement to invest in resilience. These chapters also challenge stakeholders to evaluate the equitable nature of resilience investments and the extent to which diverse populations are procedurally engaged in the distribution of recovery and resilience resources.

The final group of chapters provides a broad set of contexts that underscore the complexity of society's vulnerabilities and responses to COVID-19. Many of these chapters offer case studies that highlight everything from international public health policies to specific experiences associated with vulnerable populations. Finally, the book concludes with a concept that underscores all of the experiences associated with COVID-19—leadership. In this regard, the human dimensions of the design and management of resilience are central to any framing of risk and resilience.

Together, this book offers an expansive and critical perspective on the nature of systemic risk and resilience in the age of COVID-19. The chapters herein offer a diverse range of disciplinary perspectives that both expand the horizons of resilience scholarship, while also advancing a measure of empirical maturity in its application. As public and private stakeholders convene to plan recovery efforts, this book serves as a foundation for driving strategic knowledge in the advancement of a more sustainable and equitable collective future.

Disclaimer: The views and opinions expressed in this article are those of the individual authors and not those of the U.S. Army or other sponsor organizations.

Reference

Trump BD, Linkov I, Hynes W (2020) Combine resilience and efficiency in post-COVID societies. Nature 588:220. https://doi.org/10.1038/d41586-020-03482-z

Chapter 2
Ten Strategies for Leadership During COVID-19: A Plan of Action for Decision Makers in Times of Critical Change

Thomas P. Bostick

Abstract America is in shock. To date, nearly a quarter of a million Americans have died from COVID-19. In total, the United States has reported over 8 million cases, more than any other country in the world. After a slight lull in late August and September, daily cases are again on the rise, reaching the highest number (more than 68,0000) since July's peak. The economy is also struggling, with businesses reeling from the rapid and unexpected organizational and financial challenges wrought by the pandemic. Only about half of the 22 million jobs lost when the pandemic first struck have been recovered—in neither equal quality nor quantity. The number of Americans seeking employment benefits is at a historic high. Meanwhile, Congress has made little progress on a COVID-19 relief package.

Keywords Leadership during crisis · Leadership during COVID-19

America is in shock. To date, nearly a quarter of a million Americans have died from COVID-19. In total, the United States has reported over 8 million cases, more than any other country in the world. After a slight lull in late August and September, daily cases are again on the rise, reaching the highest number (more than 68,0000) since July's peak. The economy is also struggling, with businesses reeling from the rapid and unexpected organizational and financial challenges wrought by the pandemic. Only about half of the 22 million jobs lost when the pandemic first struck have been recovered—in neither equal quality nor quantity. The number of Americans seeking employment benefits is at a historic high. Meanwhile, Congress has made little progress on a COVID-19 relief package.

Thomas P. Bostick—Lieutenant General (Ret.) Former Chief of Engineers and Commanding General of the U.S. Army Corps of Engineers.

T. P. Bostick (✉)
Arlington, VA, USA
e-mail: tbostick@bostickglobalstrategies.com

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_2

Public health experts, epidemiologists, and infectious disease specialists warn that as students return to school, numbers rise, and cold weather sets in, the United States could be heading for as many as 400,000 total deaths by February. At more than half a year since the crisis began, now is the time to identify and develop those universal crisis responses that can be implemented immediately by organizational leaders and decision-makers to respond to the pandemic.

2.1 Key Questions to Ask

The following are key questions which decision makers must ask themselves:

- What strategies will protect key elements of an organization?
- What specific leadership skills and traits must come into play during the crisis?
- What methods can leaders implement to balance the safety of their people with the health and even survival of their organization?
- What steps can leaders take in the short-term?
- How can leaders prepare for recovery and the long-term?

Leadership during a crisis requires strategies that result in a plan of action for decision-makers in times of critical change. I am no stranger to national or global crises having led a major organization and thousands of employees both in the United States, as well as around the world. Each crisis has taught us valuable lessons, inspired us to develop powerful tools, and showed us how to not only survive but thrive and become more resilient. We don't have to look far to find strategies that will allow us to operate at our best in this present pandemic. We have strategies that have already been developed, tested, refined, and re-tested during past national and global emergencies which can serve us well during this most recent and challenging crisis.

During the 9/11 crisis, we were also faced with an unprecedented situation. At that time, I served in the National Military Command Center where our small team was responsible to the President and the Secretary of Defense for the immediate actions in response to the tragic events of that day. Our country learned how to respond to the many challenges of that period. As the Chief of Engineers and Commanding General of the U.S. Army Corps of Engineers (USACE) during the devastation brought about by Hurricane Sandy, USACE worked with the Federal Emergency Management Agency (FEMA) in the response effort side-by-side with the nation's leadership, our military, our Governors, Mayors, and other first responders. During that period the country developed and tested multiple strategies at every level of leadership.

While the current crisis is very different from 9/11 and Hurricane Sandy, the strategies put in place before, during, and after these crises can be helpful for government and business leaders today. Although every crisis brings along with it a number of different variables, and there are no cookie-cutter solutions for leadership actions and operating strategies during a crisis, there are still key strategies that can and should be implemented.

(1) **Communicate current facts through multiple avenues of communication**.

Experts should be visible and communicate often. Expert-driven information is based on the facts at hand, on professionally determined assumptions, and on the best possible plans to address the crisis. Communications should be clear, concise, consistent, and understandable to a broad audience. Leaders should communicate often and reassure the workforce and the public that the appropriate actions are being taken to steady the ship during turbulent times. In the private sector, where appropriate, Boards of Directors should engage with company leadership frequently to address concerns. This is the time for leaders to lead and to frequently be vocal and visible.

The leadership of an organization should mobilize multiple avenues of communication utilizing a combination of internal and external resources and virtual and old-school tools to ensure that their teams are receiving the most up-to-date and accurate information possible and have organizational support to share that information with their own circles of influence.

(2) **Crisis leaders should set an example for their organization**.

In this crisis, there is much that leaders can and should do to set an example for individual responsibility including maintaining social distancing, wearing masks properly, placing themselves in self-quarantine or self-isolation when appropriate, communicating with loved ones frequently, and assisting those in need. Unfortunately, during times like this, some people and organizations will take advantage of the crisis to make a profit, for instance, through price gouging. Those even more desperate will begin to rob from stores. Leaders must address these offenders quickly and communicate to the public that this type of behavior will not be tolerated.

In parallel, leaders must help the nation ensure it has basic necessities such as water, food, shelter, medical supplies, and support available so that people do not feel alone and desperate. Leaders should evaluate the capabilities of their organizations and organize teams to help pivot from standard organizational products and services into areas of emergency supply or support.

(3) **Organize for battle**.

Military leaders must always be prepared to fight different types of battles. Leaders organize and build teams for the specific battle at hand. Each organization in the public and private sector must adapt to handle the crisis at hand at its own level. Leaders must reorganize their teams and recruit their best experts as part of the strategy employed to win this particular mission.

The teams in an organization that also act as first responders will need support. We are already seeing the effects of insufficient support for healthcare workers. They are overworked. They fall ill themselves. They see the psychologically and physically devastating effects of COVID-19 first-hand. They need more support than others so that they can focus on the fight. A-team players will continue to be overworked and will need backup. Leaders need to carefully assess the needs of their personnel, especially their front-line staff, and create backup teams, reaching out even to retired members, to support the efforts of the organization.

(4) **Set up a "War Room"**.

Each organization should have a "war room." The war room should be the hub of all information and decision-making where organizations track the pertinent facts, assumptions, and ongoing execution of the planned strategy. All pertinent information should be fed into the war room, which should operate on a 24/7 basis during the crisis. Traditionally the war room supports the commander, for example, the president, governor, mayor, and other national and community leaders.

However, the installation of a war room should not be limited to the highest levels of government. Leaders, corporations, and organizations should also set up war rooms to support their crisis operations programs and communication streams with their employees, customers, vendors, and shareholders. Just as there should be seamless and rapid digital communications across the federal agencies and from the federal agency level to the state and local levels with the officers of governors and mayors, so should that extend to leaders and C-suite executives in the private sector.

(5) **Reinforce the chain of command and decision rights**.

The buck must stop with the leader for significant decisions during a time of crisis. However, there are day-to-day decisions that must be made that do not necessarily rise to the level of the most senior leader. Decision-making authority must be set up and made clear to all as to who in the organization has the authority to make which decisions. What decisions fall into the authority sphere of a supervisor, a department head, a middle manager, a vice president, and so on? All these authorities must be decided, delegated, and communicated. Without clear decision rights at every level, the organization can experience serious miscommunication and delays in taking important actions.

(6) **Leverage existing organizational structures and known processes**.

It is both reassuring and encouraging to see the country leveraging the FEMA, the USACE and the Department of Defense (DOD), in addition to our health care experts. The structure, processes, and response expertise in these types of organizations can assist our medical and public health experts. States and local public and private institutions can do something similar.

Leaders should actively seek out and leverage existing crisis experts and their organizations. For businesses that have a Chief Operating Officer (COO), designing crisis response structures around these entities is ideal since the COO generally touches most parts of the company. All guidance and direction within the company should come from the crisis operation center on behalf of the CEO.

(7) **Take the politics and bureaucracy out of the crisis**.

While removing politics might be challenging, particularly during an election year, now is not the time to try to gain political points by blaming the other side. The country needs all hands on deck.

How should disagreements be handled? Leaders should disagree behind closed doors and not battle publicly merely for political advantage as this type of behavior causes the "troops" to lose faith in their government and business leaders.

(8) **Leaders should reinforce the concept that a simple "thank you" goes a long way**.

During a crisis, many people are working overtime—risking and sacrificing much. Some are putting their own lives on the line to help others. They do not expect much in return, but they do want to know that their effort matters. Leaders should encourage their teams and show by example that regularly thanking those in the fight is essential in any organization, but is even more important during times of crisis. Every member of the organization can do their part by reaching out by phone or virtually to those people who are making a difference.

Again, leaders need to be visible and prominent on the front line. For the military, we want leaders at the critical place on the battlefield where their leadership and experience might make a difference. This applies to the private sector as well. Business leaders, for example, should ask themselves a few important questions at the start of every day: Where on our battlefield should I be today? Where can I make the most difference? What are the actions that only I can take?

(9) **Build tomorrow's leaders during today's crisis**.

This type of crisis will repeat itself. Take advantage of the crisis to train the next generation so they are better prepared for the next crisis. Place your most talented junior leaders in critical crisis response positions. First, recognize that leaders cannot handle both the crisis and the day-to-day operations at the same level as they did prior to the crisis. Do some corporate triage. Identify and make the decision to stop doing those "normal" activities that will not affect the organization in the near term. Then have junior leaders assist by stepping up to handle some of the day-to-day duties of running the organization, so that other more senior leaders can focus 24/7 on the crisis at hand.

During Hurricane Sandy, we brought young officers from the USACE's school at Fort Leonard Wood, Missouri into New York City to assist in the recovery. For the next decade or more these young officers will use that experience to better understand how to operate in a crisis. The public and private sectors can now do the same. Who are your next-generation leaders who need to learn from this experience so they can provide the leadership and guidance necessary when the current leadership has moved on?

(10) **Conduct After-Action-Reviews**.

Conduct After-Action-Reviews (AARs) regularly to avoid repeating mistakes, to share lessons, and to improve each day. The Army created the AAR at the National Training Center where units simulate repeated combat operations. The AAR is an open and collaborative process after a battle where leaders discuss the challenges they experienced. They ask themselves, “What happened? Why did it happen? What can we do to prevent it from happening again?” During a crisis, leaders in all organizations should conduct regular AARs, even as the crisis is ongoing. Then, after the crisis is over, a detailed series of AARs will help the organization prepare for the next crisis.

Additionally, leaders should think about what the organization did well during the crisis and whether that strategy, solution, or action should continue and be incorporated as a matter of regular practice. For example, if the war room concept works for an organization, the leader may wish to run day-to-day non-crisis operations from the war room to be in a position of constantly training the team. A business organization might want to implement a policy of working from home one day a week or month to ensure this remote working capability is tested and fine-tuned on a regular basis. Finally, the rest of the questions should center on what the organization stopped doing because of the crisis. Was there any negative impact of stopping that activity? If not, then consider whether your organization should restart old activities, processes, and procedures post-crisis.

2.2 Conclusion

During a crisis, we always see the best of America coming together as one team to advance the interests and well-being of our country. This is a crisis like no other and will require the very best of America to fight through it. There is no one simple solution, no fast, easy fix or panacea. However, there are strategies and actions which leaders can implement today which will assist their organizations not only during the time of the immediate crisis but in the recovery period which will follow.

Our leaders know how to lead. Our teams know how to work together effectively. We know how to communicate, stay informed, and support each other as we all work toward the ultimate goal of getting through this crisis even stronger than before. These strategies will help make our people, our leaders, and our country more resilient during this crisis, and those that follow.

Chapter 3
Some Elements of Analysis of the Bibliography on Risk and Resilience on COVID-19

Myriam Merad

Abstract The COVID-19 crisis generated in a few months an unprecedented mobilization in our contemporary history. In the scientific world, this mobilization has taken the form of a massive publication of special issues of newspapers, opinion papers, position papers, critical analysis, methodological proposals and even the sharing of ongoing experiments. The review times allocated by the newspapers have been greatly shortened and many platforms and publishers have made these papers accessible to all audiences. In what follows, we will present a summary of the bibliometric analysis of the publications on COVID-19 on three mains topics: "Trends & Socio-economic impacts", "Risk Governance" and "Science-Policy interaction". This analysis revealed: A strong concentration of paper' publications on the topic of health risks prevention to individuals. A weak integrated and systemic analysis of the COVID-19 crisis. A strong mobilization of health expertise during crisis management' decisions and the weak representation of expertise in the humanities and social sciences. The poor characterization of the socioeconomic consequences of the crisis on verities of economic sectors and on different scales of territories. A strong need to share experience on the frontiers between science, politics and decision making as experienced and mobilized within countries and cultures.

Keywords Publications on COVID-19 · COVID-19 literature review

3.1 Introduction

The first wave of the COVID-19 pandemic began to attract particular attention, for European countries, in January 2020. This pandemic seems to have taken by surprise the States testing their risk prevention and crisis management systems. More than a large-scale health crisis, COVID-19 revealed the flaws and vulnerabilities of

M. Merad (✉)
CNRS, UMR LAMSADE (Université Paris-Dauphine)—PSL, Paris, France
e-mail: myriam.merad@lamsade.dauphine.fr

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_3

countries, territories and economic sectors and revealed the limits of our management and governance systems.

The links between policy and science proved to be at the heart of communications to the general public, whose daily lives have been disrupted by health emergency management measures. The increase in the number of people infected, hospitalized and deceased has been communicated daily to reveal the seriousness of the situation. At the same time, however, there was still a significant lack of clarity about the social and economic consequences of this crisis. In April 2020, the price of oil became negative, leading to the destabilization of the economies of the countries and the instability of the States.

In this context, we wanted to explore the scientific contributions related to the COVID-19 pandemic: (a) induced socio-economic issues, (b) the links between science and decision making and (c) the theme of risk governance. The COVID-19 crisis generated in a few months an unprecedented mobilization in our contemporary history. In the scientific world, this mobilization has taken the form of a massive publication of special issues of newspapers, opinion papers, position papers, critical analysis, methodological proposals and even the sharing of ongoing experiments. The review times allocated by the journals have been greatly shortened and many platforms and publishers have made these papers accessible to all audiences.

In what follows, we will present a summary of thebibliometric analysis of the publications on COVID-19 and some key observations. This analysis was based on the CNRS bibliographic research platform (https://bib.cnrs.fr/) and the use of two tools: Vosviewer and Gargantext.[1] The paper will discuss the follow-up to this first literature review on the analysis of the governance of the COVID-19 crisis on European countries.

3.2 Brief Literature Review

To date (31/07/2020), more than 30,583 papers have been published on COVID-19 and listed on Scopus, including 1 in 2018, 22 in 2019, 30,548 for 2019 and 12 in 2021. Web of Science (WOS) identifies 19,777. These differences in paper referencing is due to the presence of a larger paper database within Scopus. Both databases have paper registration errors. Thus, some papers referenced as being published in 2018 or even for some in 2010 on COVID-19 are either the result of an author referencing error or a referencing reception attributable to these two tools. Analysis of the documents referenced in WoS highlights the strong dominance of publications on COVID-19 on health-related topics (see Fig. 3.1).

Although the main specialty sought during the mobilization of scientists in crisis management is "infectious diseases", this theme of publication comes in fourth

[1]https://gargantext.org.

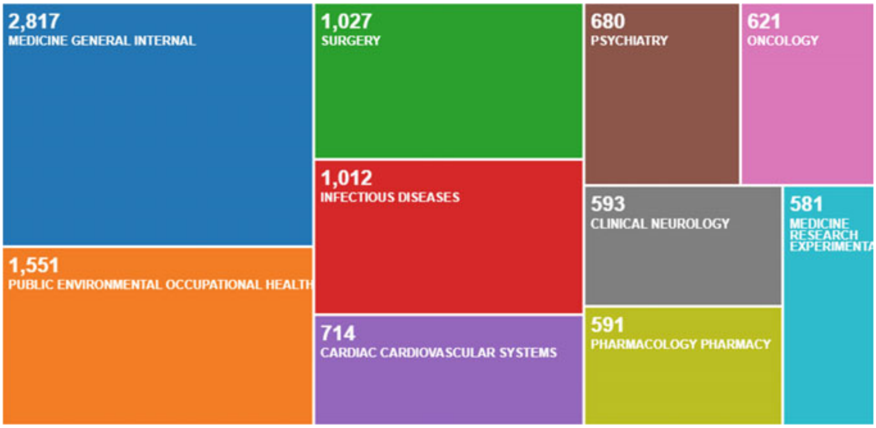

Fig. 3.1 Publications on COVID-19 according to WoS categories

place with more than 1012 publications. The themes of "general internal medicine", "public environmental occupational health" and "surgery" come respectively in first position (2,817 publications), (1,551 publications) second and (1,027 publications) third. More than 680 publications have been produced on the theme of "Psychiatry" highlighting the interest in the indirect effects of COVID-19 crisis management.

The USA followed by China dominates in terms of the number of publications. We would expect a higher level of publication from China given that this territory was the first to be exposed to the COVID-19 pandemic. In Europe, Italy dominates in terms of number of publications with more than 2,427 papers. Italy is followed by England, Germany, France and Spain (Fig. 3.2). These discrepancies in terms of number and rate of publication could be explained by different publication cultures or even different approaches to confidentiality from State to State.

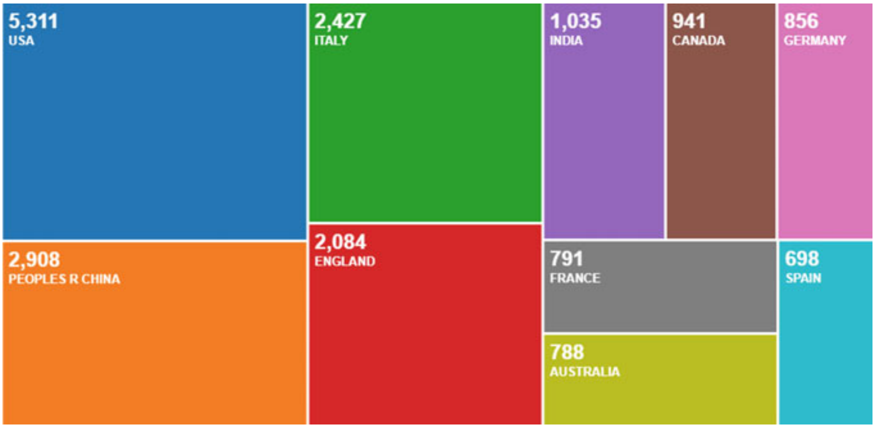

Fig. 3.2 Publications on COVID-19 by countries

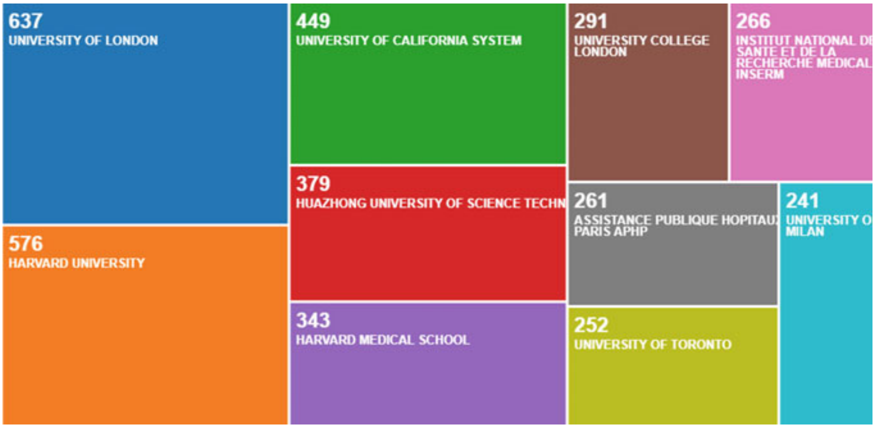

Fig. 3.3 Publications on COVID-19 par organismes

The organizations the most active in publishing publications are respectively Harvard University, Harvard Medical School and University of California System (USA), University of London (UK), INSERM et APHP (France), Huazhong University (Chine) et University of Milan (Italie). Organizations in Anglo-Saxon countries find it easier to make their work accessible by avoiding the costs (time and means) induced by translation needs.

The number of papers falls to 12,382 on Scopus and 3,037 papers on WoS when the query is about risk and COVID-19. The analysis of the distribution of these thematic papers shows that the risk theme brings to light topics such as management sciences (1,5%), psychology (2,4%), environmental sciences (3,3%) or social sciences (4,8%) (Fig. 3.4).

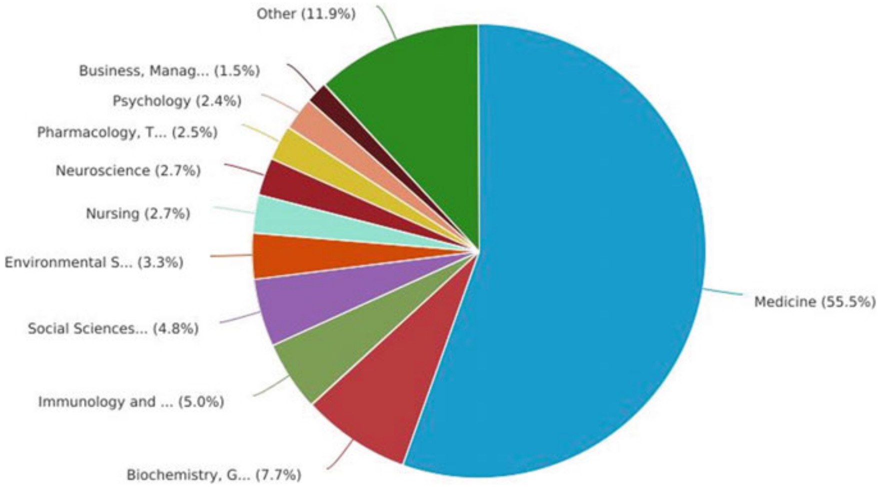

Fig. 3.4 Publications on COVID-19 and Risk by subject area on Scopus

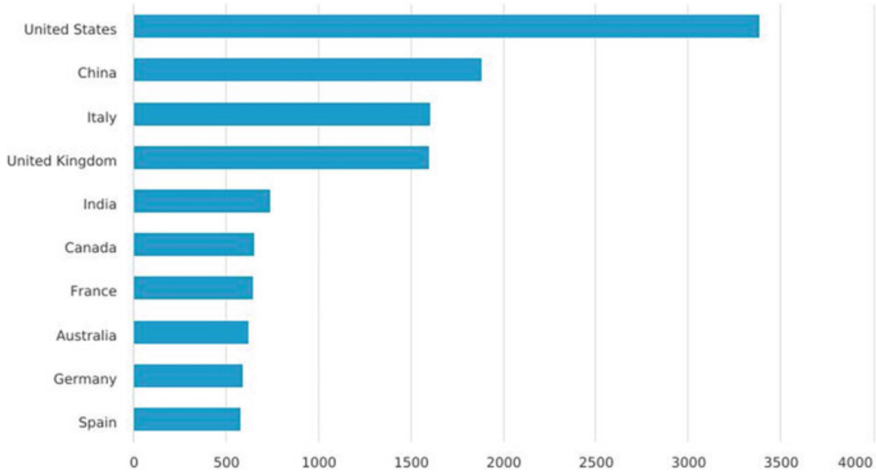

Fig. 3.5 Publications on COVID-19 and Risk by countries on Scopus

The distribution of publications by field shows that the problem of the COVID-19 crisis is considered above all as an individual health problem in the restricted sense of the term.

The USA, China, Italy and England dominate in terms of number of publications (Fig. 3.5).

The organizations that have published the most on these topics are ranked in order Huazhoug University (Chine), Tongji Medical College (Chine), Harard Medical School (USA) andINSERM (France).

3.3 Specific Investigations

The field of humanities and social sciences being, as we have seen, weakly represented in the publications, we wanted to observe the way in which three objects of analysis, by nature transdisciplinary and multidisciplinary, have been taken into account in the publications:

(A) Risk and crisis governance.
(B) The link between science and decision-making.
(C) The consideration of socio-economic aspects.

In this regard, we have investigated eight themes[2]:

[2]Documents are made available by contacting myriam.merad@lamsade.dauphine.fr.

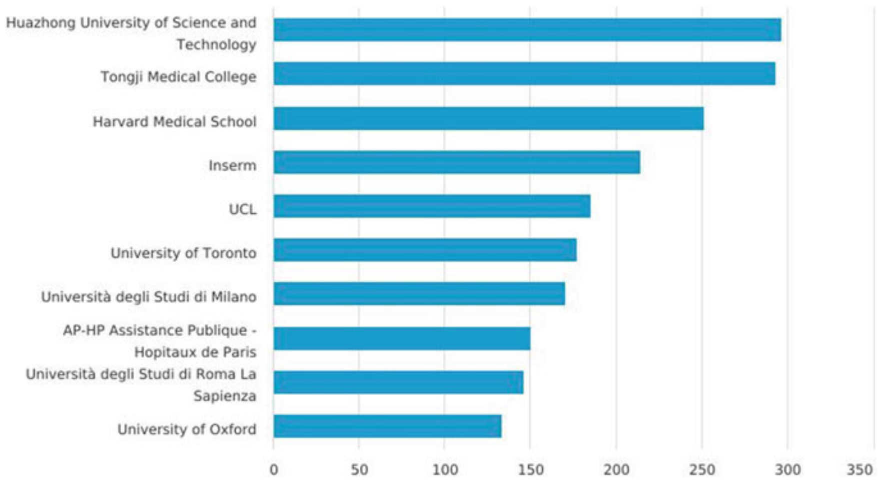

Fig. 3.6 Publications on COVID-19 and Risk by affiliation on Scopus

(A) Risk and crisis governance:

- Covid-19 and "risk governance" on a collection of 182 papers available in the document covid risk gov.ris.
- Covid-19 and "risk communication" on a collection of 111 papers available in the document covid-risk comm.ris.
- Covid-19 and "risk assessment" on a collection of 629 papers available in the document Covid-Risk Assessment.ris.
- Covid-19 and "risk management" on a group of 221 papers available in the document covid-risk management.ris.
- Covid-19 and "risk crisis" on a group of 1110 papers available in the document Covid-Risk-Crisis.ris.
- Covid-19 and "risk and vulnerability" from a grouping of 249 papers available in the document covid-vulnerability-risk.ris.

(B) The link between science and decision-making:

- Covid-19 and "Science, expert and policy" on a collection of 221 papers available in the document science-policy-expert-covid.ris.

(C) The consideration of socio-economic aspects:

- Covid-19 and "Socioeconomic" on a grouping of 134 papers available in the document Covid-Socioeco.ris.

These objects of analysis represent less than 6% of the published literature on COVID-19.

1. **Graph analysis**

The graph developed from the publications on the socio-economical theme highlights the presence of three strong poles (Fig. 3.7). The first is the consequences (e.g. stress and mental health) on society of the containment measures taken as a result of the spread of the epidemic in China (Fig. 3.7b). Issues such as “anxiety symptoms”, “mental health”, “consumers” attitudes are investigated. The Chinese case remains the main subject of the publications.

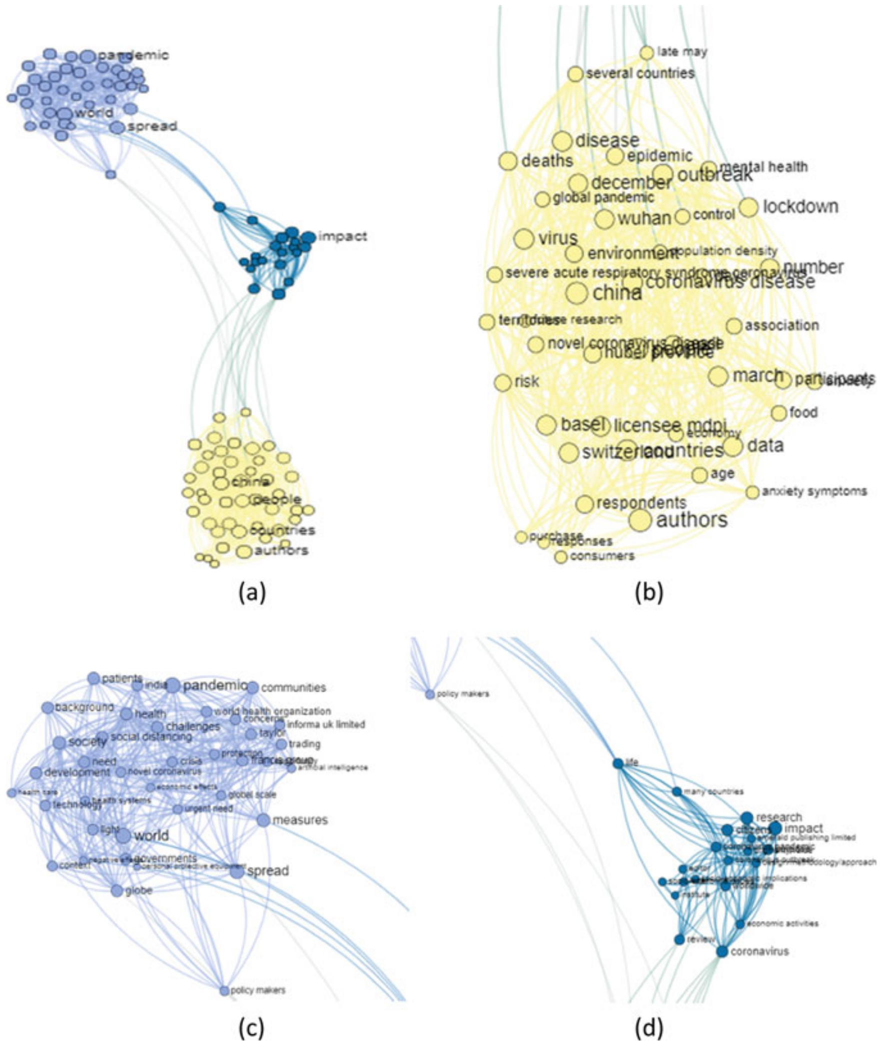

Fig. 3.7 Graph on the 134 papers of the COVID-19 and socio-economics theme (Gargantext)

A second pole is around the need pointed out by the authors to work on socio-economic aspects (Fig. 3.7b). It appears from the papers that this is more of an injunction than a proposal for a method or analytical results obtained by the authors.

A third pole is focusing on the use of technologies (e.g. artificial intelligence) (Fig. 3.7b). AI is promoted as a means of predicting economic impacts as well as a means of estimating the effect of crisis management measures.

The economic effects studied take into account the negative consequences of the pandemic as well as the opportunities offered by it. The question of the impact on the economic sectors (e.g. the housing sector, the food sector) extends the scope of the publications to effects that go beyond the impacts on individuals. The graph drawn from the 182 papers on the theme of risk governance (Fig. 3.8) highlights four main themes. The first relates to the issue of preparing for and anticipating these large-scale crises. The second is the issue related to the effect of uncertainty on the crisis and on economic sectors. The third theme is that of taking values into account. The fourth and final theme is that of decision-making and its proportionality in the territories.

The place of the European Union is discussed as a territory of cooperation and coordination in terms of science, especially when mobilizing experts, as well as in terms of health policies and crisis management. The theme of risk communication (111 papers) highlights three poles (Fig. 3.9). The first (in blue) and the type of methods and protocols used (mainly online surveys, questionnaires, and polls) as

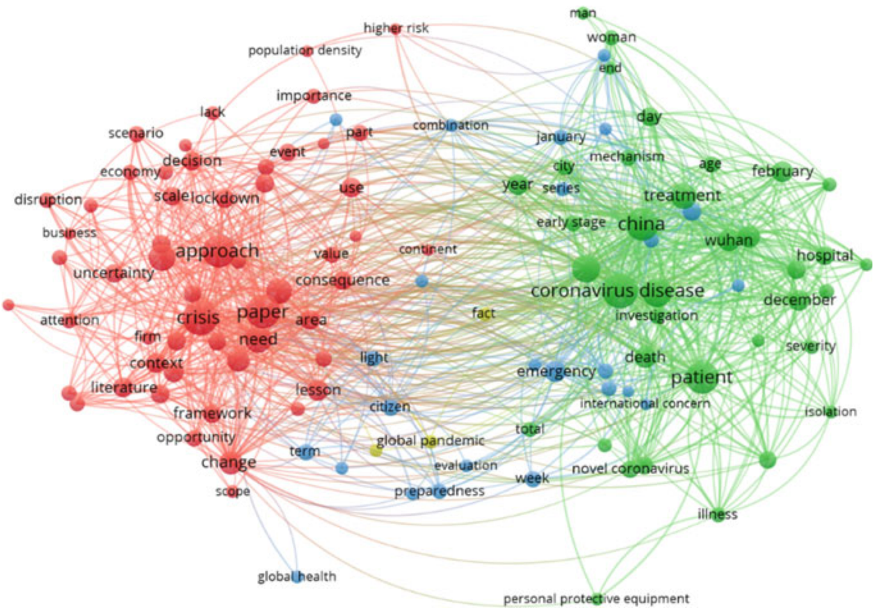

Fig. 3.8 Graph on the 182 papers of the COVID-19 theme and risk governance (VOSviewer)

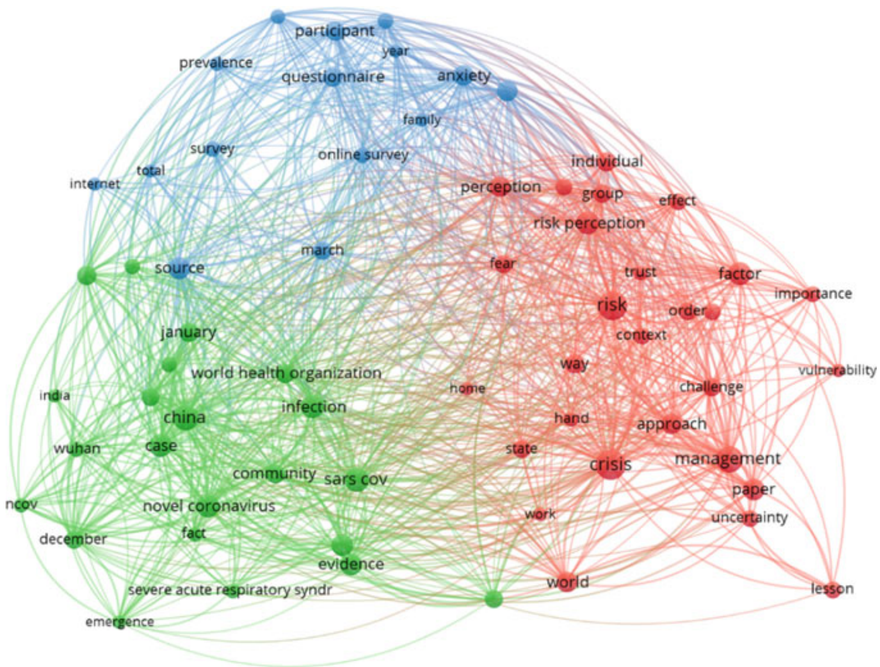

Fig. 3.9 Graph on the 182 papers of the COVID-19 theme and risk communication (VOSviewer)

well as the major theme investigated (anxiety). The second pole (in red) concerns the perception of risks, individual and collective perception of the crisis, fears and vulnerabilities. The third pole is organized around China and the spread of SARS COV.

The analysis of the 212 papers on the science and policy theme does not reveal any significantly recurring themes (Fig. 3.10). The COVID-19 crisis appears mainly as a health problem managed by governments.

The papers on risk assessment are dominated by the theme of assessing health risks to patients and proportionate therapy (Fig. 3.11). The same observation prevails for papers on the theme of risk management (Fig. 3.12).

The papers on the theme "crisis and risks" (Fig. 3.13) reveal two dominant themes: health following acute exposures and health considering chronic effects (e.g. anxiety). In what follows, we will discuss some of the key aspects that emerge from this first textual analysis of scientific papers addressing socio-economic dimensions, risk governance and the link between science and decision making.

2. **Is the COVID-19 pandemic considered as a health disaster in the literature review?**

This question may seem legitimate if we were to define a health disaster as a situation leading to a major crisis in which the existing health response appears, to

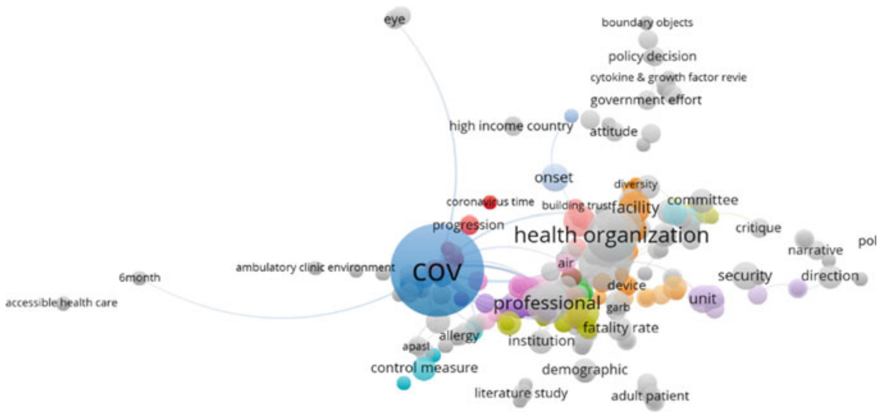

Fig. 3.10 Graph on the 212 papers of the COVID-19 and science and policy theme (VOSviewer)

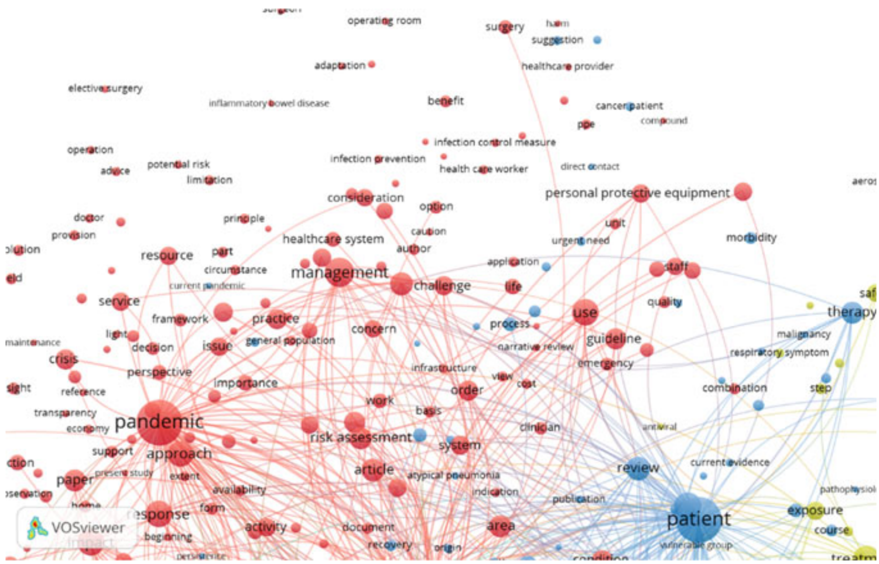

Fig. 3.11 Graph on the 212 papers of the COVID-19 theme and risk assessment (VOSviewer)

some extent, to be insufficient to deal with the influx of victims. In view of this situation of tension, this can lead to a severe disorganization of the usual health care system, with a limited ability to cope and mitigate pandemic impact. In short it is a health system crisis within a pandemic crisis. Similarly, a health disaster is distinguished both by the large number of victims, the illness severity and by the delay in their appearance. It should be noted that different hazards can cause a health disaster: natural, technological, biological and societal.

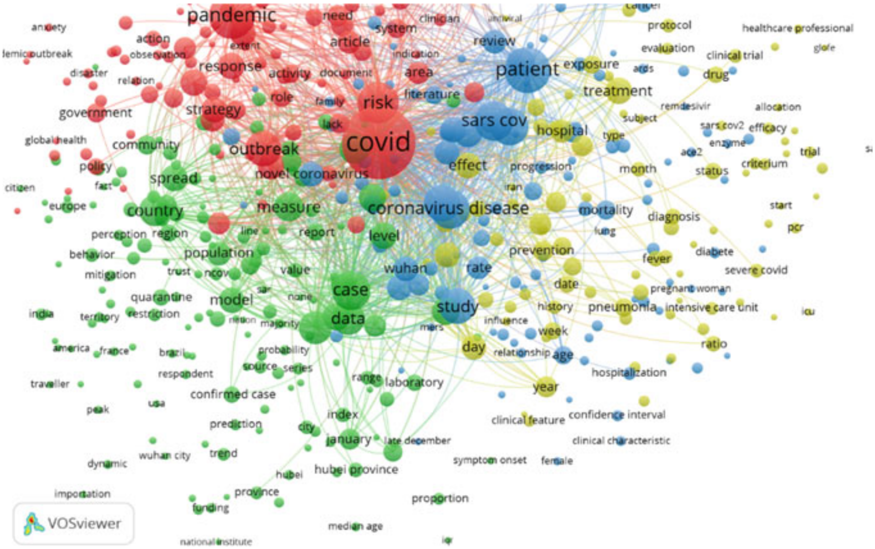

Fig. 3.12 Graph on the 212 papers of the COVID-19 theme and risk management (VOSviewer)

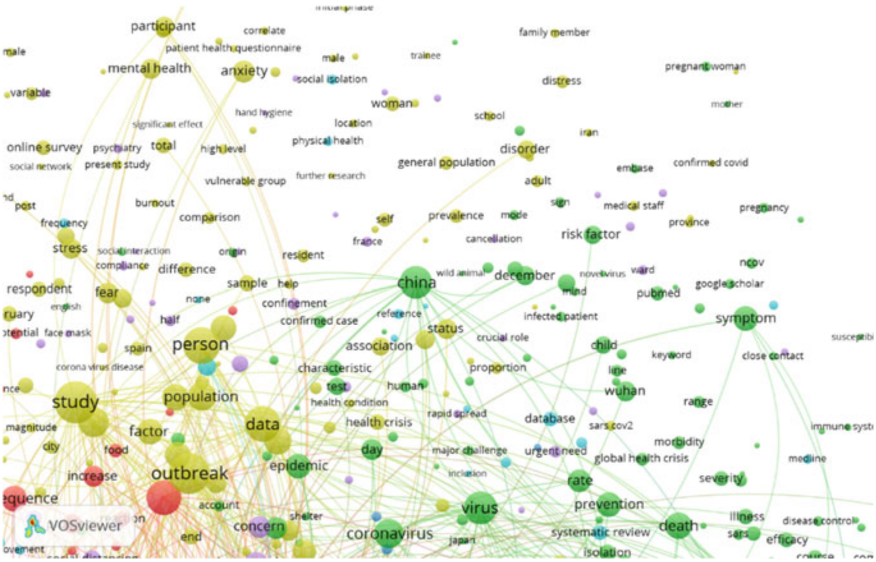

Fig. 3.13 Graph on the 212 papers of the COVID-19 theme and risks and crises (VOSviewer)

In view of this definition, the literature review revealed that it is possible to consider that the situation of a health disaster depends on two main dimensions in interactions:

- the pandemic spread and impact on people with the rate of patient arrivals, the number of patients, and the severity of illness.
- the response capacity, vulnerability and resilience of the health care system,

Numbers, illness severity, and time are indeed three major factor that characterize the pandemic impact on different sets of response capacities. In the case of the COVID-19 pandemic, the casualties per country have been, and continue to be, spread out over time, putting existing health facilities (e.g. number of beds, respirators, emergency services and hospitals …) under strain. For instance, the number of respirators was a key factor to manage severely ill patients. The terms "disasters" or "catastrophes" have been poorly discussed in the papers. The use of this term seems to refer more to a legal framework mobilized by the exposed countries rather than as an operational concept.

3. **Is the COVID-19 pandemic a health crisis with respect to the literature review?**

Health crises are situations resulting from a strain on health systems where events, actually or potentially affecting a large number of people, affect health and may possibly increase the significant factor of mortality or excess mortality. The state of "health crisis" is declared by the States. Some of these crises may give rise to health scandals in situations where citizens' confidence is undermined. The term "crisis" is widely used in the papers. However, the use of this term is not exclusively linked to the term "health‶. Indeed, the crisis is not only health-related, but also economical, societal, political and even ethical ones.

4. **Is the COVID-19 pandemic a health emergency with respect to the literature review?**

A state of health emergency is an exceptional legal provision that is intended to enable a State to respond to an epidemic, pandemic or health disaster that endangers the country. More broadly, the "State of Emergency "qualifies a measure taken by a government in the event of imminent danger in a country or region. Within the framework of the application of this measure, certain fundamental freedoms may be restricted, such as freedom of movement or freedom of the press. In the large part of the papers, the term "emergency" seems to refer more to the sensitivity and criticality of a situation than to the activation of regulatory measures.

5. **What risks are considered with respect to the literature review?**

In order to understand how the authors have studied the risk and crisis governance and how they have discussed (or not) categories of scientific expertise, we first explored how the term "risk" has been used and associated with a qualifier. In a large majority of cases, the term risk is associated with the term "health".

Few papers associate it with the terms "economic", "environment" and "social".

Surprisingly, the term "uncertainty" has been very little used in the papers. Uncertainty is in some cases mobilized to characterize areas of unknowns on the sensitivity or vulnerability levels of individuals exposed to COVID-19. In other cases, uncertainty concerns the effect of the economic and social consequences of the COVID-19 pandemic on individuals and territories, on the forms of activation of risk mitigation measures, and on the science and consequences of decisions. The term "ambiguity" was poorly used in the papers. Few papers refers to it indirectly by recounting the existence of contrasting sources on the number of deaths.

Some papers revealed those they considered to be vulnerable populations. This is the case of.

- Elderly population.
- Population with chronic disease.
- Emigrant population.

Some papers similarly revealed what they considered to be socio-economic vulnerabilities. For example, some European countries reported on the vulnerability of their economy due to their heavy dependence on an export or import economy.

6. **What risk prevention and mitigation measures are being taken with respect to the literature review?**

Most of the measures taken by countries during COVID-19 crisis and discussed in the papers are those to reduce the likelihood of the spread of the pandemic or to reduce the exposure of vulnerable people. These measures focus primarily on the acute human health risks that are induced by the spread of COVID-19.

In the statement of measures in the papers, it was noted that some countries have put in place an integrated approach to managing risks to both health and the economic sector. This does not mean that economic concerns have not been considered by the other countries. On the contrary. Analysis of the use of the term "economy" in the papers shows that it emerges as a concern of the first order for the majority of authors and countries.

Depending on the case, non-compliance with measures to prevent or reduce risks has led to sanctions. In other cases, voluntary action and individual responsibility have been the main focus. Thus, the Swedish response for example largely prefers voluntary and persuading measures rather than severe restrictions, limitations and prohibitions.

7. **What are the approach to systemic risk prevention that were discussed in the literature?**

A global analysis of the papers on COVID-19 highlights three dominant conceptions in the literature on systemic risk management and governance. The first (Fig. 3.7) is an approach that consists of managing the risks associated with the COVID-19 pandemic by focusing on individuals (methodological individualism). In this case, society is considered to be a sum of individuals. In this approach, the vulnerable system is "the individual". The risks taken into consideration are mainly acute risks and risk mitigation and prevention strategies are mainly related to reducing exposures, vulnerabilities or the severity of consequences. In view of the nature of the risk under consideration, containment measures appear to be the most discussed and the most activated by States.

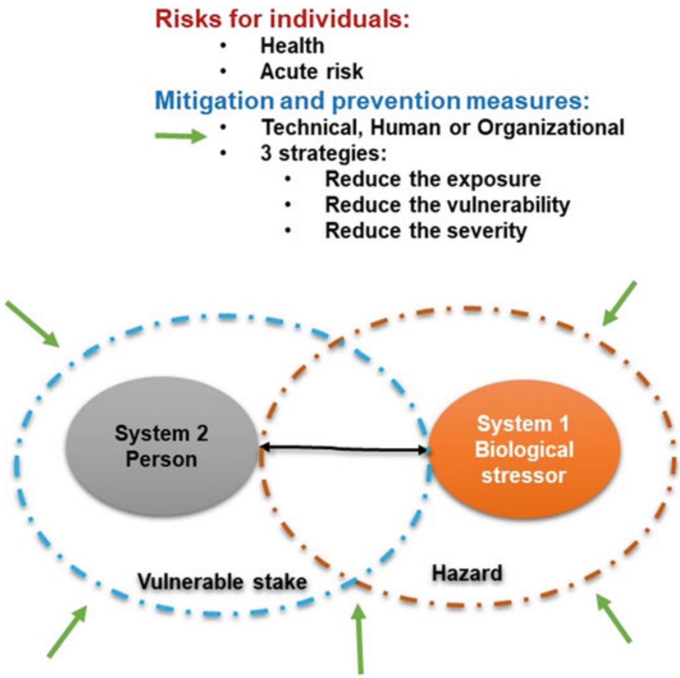

Fig. 3.14 Individual based approach to systemic risk prevention

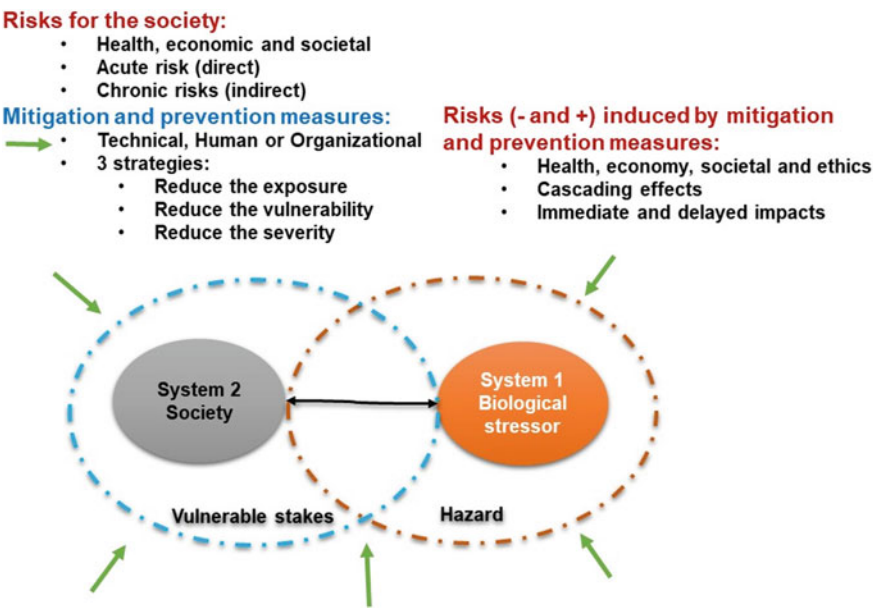

Fig. 3.15 Society based approach to systemic risk prevention

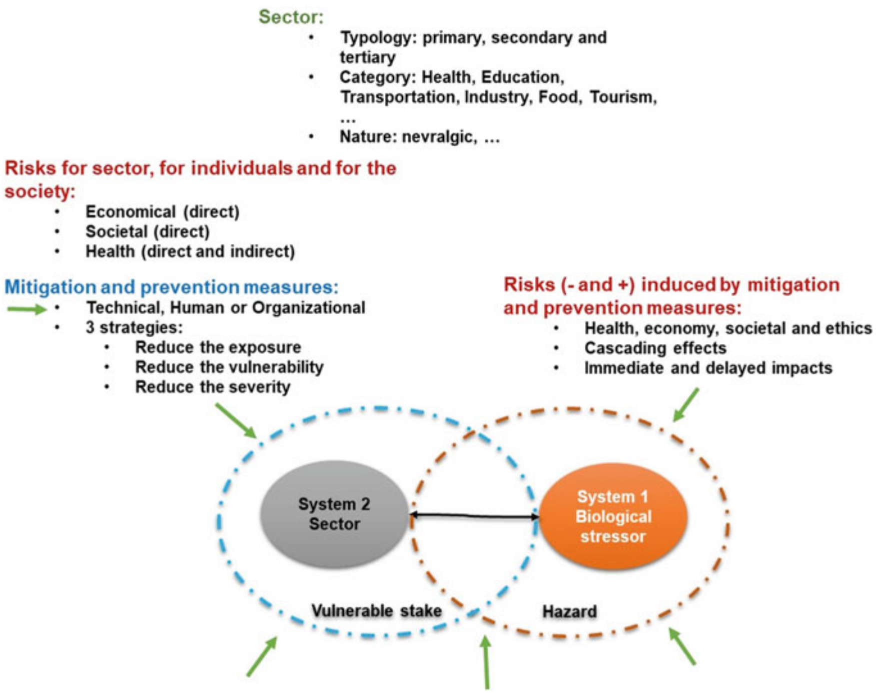

Fig. 3.16 Sectorial approach to systemic risks

The second (Fig. 3.8) is an approach to managing the risks associated with the COVID-19 pandemic by focusing on society (methodological holism). Since society is more than the sum of individuals, the risks considered are linked to health, economic and societal issues. In this approach, the application of a risk prevention or mitigation measure induces risk transfers to sub-systems of the “society” system and cascading effects. Thus, only few publications seems to follow this approach. These publication have in common discussion on the modalities of application of containment measures and an anticipation of the direct and indirect consequences of measures put in place to reduce acute risks.

The third (Fig. 3.9) and final approach is an approach that consists of managing the risks associated with the COVID-19 pandemic by focusing on the economic sectors (methodological holism). The risks considered are linked with health, economic and societal issues. In this approach, the objective is to reduce the risks while thinking about the continuity of activity (resilience) of the different economic sectors or the different functions of the societal system.

Although the various papers have included considerations related to the different economic sectors, little information is provided on business continuity plans and sector resilience plans.

3.4 Discussion and Conclusions

The first wave of COVID-19 pandemic spread at different rhythms during the first quarter of 2020. Indeed, countries have faced different intensities and dynamics of pandemic spread and have started with different strengths and vulnerabilities. Each of these countries has developed an original response.

In order to understand the different dimensions of the COVID crisis, we decided to first explore the scientific literature published at the end of July 2020. This analysis focused on exploring the papers that have been published on COVID-19 on three mains topics: "Trends & Socio-economic impacts", "Risk Governance" and "Science-Policy interaction".

The brief bibliometric study highlights the existence of a significant number of papers published in a very short period of time and revealed:

- A strong concentration of paper' publications on the topic of health risks prevention to individuals.
- A weak integrated of systemic analysis of the COVID-19 crisis.
- A strong mobilization of health expertise during crisis management' decisions and the weak representation of expertise in the humanities and social sciences.
- A poor characterization of the socioeconomic consequences of the crisis on verities of economic sectors and on different scales of territories.

The highlighting of three standard schemes, developed in the literature, for the analysis of systemic risks related to the COVID-19 pandemic has contributed to reveal the presence of differences and similarities in the way science for decision-making has been mobilized by the different States. These differences and similarities can be summarized in several points:

- Centralization vs. decentralization of decision-making and management in the territories, for instance in the use of state of emergency, or in the definition of measures.
- The use of ad-hoc committees and groups of scientists vs. the use of existing structures of institutional scientific and technical expertise.
- Single and individual risk management vs. collective and multi-risks management in the territories.
- Risk communication by politicians vs. risk communication by scientists.

However, this seems to be more the result of the diversity of scientific, political and administrative history and culture of the States than a conjunctural choice. This interpretation can be challenged with regards to local severity and dynamics of COVID19 spread and the contingent vulnerabilities and capabilities of the health system and population.

Following the scientific literature review on COVID-19, we have been able to start an exploratory analysis in European countries that has contribute to identify six governance configurations for the COVID-19 risk and crisis at country levels. These six configurations are derived from distinct vulnerability configurations between European states and from different consequence configurations. The identification of these configurations was intended to open up the scope of the analysis of the impacts of the COVID-19 crisis to indicators other than the indicators monitored and communicated on a daily basis by the States, i.e. the number of people contaminated and the number of deaths.

Although the latter make it possible to report on the criticality of the situation by country, they quickly lock up attention and channel it towards a “botany of symptoms”, making one lose interest in exploring “the syndromes and deep-rooted causes” that contributed to exacerbate the consequences of the spread of an infectious disease. By exploring the structural and conjunctural vulnerabilities of our systems and territories, we are all questioning our ability to realize the strengths and weaknesses of our management and governance capacities in the public sphere and its testing (stress test) by disasters and crises.

The question of the accuracy and reliability of publicly available data, aggregated and made available by platforms working on open data dynamics, is a central issue. Beyond the volatility of information and indicators in times of crisis, there are also problems of dealing with the transparency and accountability of States. The fear of being compared, of being judged and blamed for its deficiencies is perhaps causing us to lose sight of the value of cooperation in which States learn from their strengths and weaknesses in the current economic climate. At this stage, a number of questions remain about the relationship between national sovereignty and European and international sovereignty in the prevention and management of large-scale and long-term crises. These same questions raise the issue of the link between a common health policy and the effectiveness of the operational variations of these common visions by each State. The COVID-19 crisis seems to have put the solidarity and cooperation networks between States to the test and thus raises the operationality of the principle of cooperation in a situation of severe economic crisis.

We have noted at this stage of our study that the following points need to be examined in greater depth. Firstly, although there seems to be a set of indicators, which has yet to be consolidated, to characterize the acute consequences on health and on the socio-economic sphere, it is still difficult to account for the chronic and delayed effects of the COVID crisis. Thus, how can we measure the effects of prolonged containment and its impact on the rise of chronic diseases? How do we account for the effect of isolation, stress and uncertainty about the future on population health?

Secondly, the analysis of the governance of the Covid crisis can only be understood by going back to the history of the management and governance of past epidemics and pandemics. This opens up a qualitative and quantitative longitudinal analysis for a better understanding of the structural and conjunctural vulnerabilities of States and Unions. Some will say that this crisis is unique in history in view of its extent over time and its systemic consequences. Although this observation remains to be validated, the particularity of this crisis seems to lie in the direct and indirect consequences of the measures taken to manage the acute health risks of COVID-19 and their impact on the transfer of risks. It is therefore necessary to consider the systemic effects of crisis management choices that could exacerbate the structural and cyclical vulnerabilities of States.

Finally, there is a need to carry out more detailed studies with the Member States at the meso and micro levels of prevention and crisis management. Within a country, regions faced a diversity of situations as well which could be clustered as well at a European level. The territories and practitioners in the field are the only holders of contextualized knowledge and chains of constraints that have made certain crisis management choices inevitable.

Chapter 4
Real-time Anticipatory Response to COVID-19: A Novel Methodological Approach

Emily M. Wells, Christopher L. Cummings, Kasia Klasa, Benjamin D. Trump, Jeffrey C. Cegan, and Igor Linkov

Abstract The SARS-CoV-2 novel coronavirus 13 (COVID-19) pandemic has revealed the technical requirements needed to enhance scientific analysis and epidemic modelling, but also the social and institutional challenges of operating in a global crisis. The large-scale and turbulent nature of the pandemic has exemplified that healthcare and public health safety organizations resilience is critical for maintaining function and community support in times of crises with unclear outcomes and implications. Conceptualizations of organizational resilience need support swift organizational decision-making that simultaneously prepares for and responds to adverse events and system strains under uncertainty. This chapter presents a modelling approach towards bolstering organizational resilience for healthcare organizations facing COVID-19 called "real-time anticipatory response," which considers how organizations concurrently prepare for and respond to the pandemic under conditions of high pressure and high uncertainty. The framework supports strategic planning based on limited information and immediate need for organizational response which can be applied to a vast array of natural disaster and other crises that require stakeholders to enact quick decisions that facilitate organizational preparation and response simultaneously

---

E. M. Wells (✉)
Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, USA
e-mail: emwells@andrew.cmu.edu

C. L. Cummings
North Carolina State University, Raleigh, USA

C. L. Cummings
Iowa State University, Ames, USA

K. Klasa
Health Management and Policy, School of Public Health, University of Michigan, Ann Arbor, USA

B. D. Trump · J. C. Cegan · I. Linkov
Risk and Decision Science Lab, Engineer Research and Development Center, U.S. Army Corps of Engineers, Washington, DC, USA

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_4

Keywords Organizational resilience · Modeling resilience · Real-time anticipatory response

4.1 Introduction

With its rapid escalation across the globe, the SARS-CoV-2 novel coronavirus (COVID-19) pandemic has revealed the technical requirements needed to enhance scientific analysis and epidemic modeling, but also the social and institutional challenges of operating in a global crisis. The large-scale and turbulent nature of the pandemic has exemplified that healthcare and public health safety organizations resilience is critical for maintaining function and community support in times of crises with unclear outcomes and implications. Conceptualizations of organizational resilience need support swift organizational decision-making that simultaneously prepares for and responds to adverse events and system strains under uncertainty, such as in the case of the COVID-19 pandemic. To be resilient in situations requiring quick need decision-making under uncertainty, organizations must concurrently prepare for and respond to crises—both anticipated and unanticipated. Organizational resilience hinges on both preparing for potential futures as well as adapting organizational response as information and situational awareness is gained.

In this chapter, we present a modeling approach towards bolstering organizational resilience for healthcare organizations facing the COVID-19 pandemic. We present a model that demonstrates "real-time anticipatory response", which considers how organizations had to concurrently prepare for and respond to the pandemic under conditions of high pressure and high uncertainty. Real-time anticipatory response offers a conceptual approach to assess organizational resilience based on existing theoretical foundations. Real-time anticipatory response includes both risk assessment and potential future scenario analysis under uncertainty, and it fits into existing organizational resilience frameworks, as it diminish uncertainty through robust modeling of futures under diverse potential crises conditions. Real-time anticipatory response can be used to assess and bolster organizational resilience through flexible, iterative, and reflexive modeling under uncertainty. The framework can be applied to a vast array of natural disaster and other crisis responses that require stakeholders to enact quick decisions that facilitate organizational preparation and response simultaneously during unfolding and uncertain crises.

Such modeling efforts support strategic planning based on limited information and the immediate need for organizational response. In this chapter, we report on our efforts to enact the real-time anticipatory response of healthcare organizational resilience under COVID-19 constraints in the highly uncertain early phases of the global pandemic. We focused on how healthcare providers and provider networks in austere and remote islands could be made more resilient to community spread of COVID-19 during the initial phases of the pandemic.

The COVID-19 pandemic is a crisis that has exemplified how critical it is for organizations to be able to manage personnel, resource, and community support in light of crises that are unpredictable and have unknown severity and implications. Due to the virus' highly transmissible nature, the COVID-19 pandemic potentiates continued surges in hospital caseloads. These surges put pressure on healthcare infrastructure and personnel, especially in communities who may be more vulnerable to natural disaster, poverty, and underlying health conditions. While there does not yet exist a widely implemented vaccine or therapeutic treatment, patients who develop severe cases of the disease are often treated in hospitals under medical supervision, some requiring the use of ventilators to support respiration (Rees et al. 2020; Rodriguez-Morales et al. 2020). Given the transmission potential and that the average in-patient hospitalization period for severe cases often exceeds two weeks (Rees et al. 2020), healthcare providers and networks of providers—herein referred to as "healthcare systems"—may be strained to maintain adequate medical personnel and resources, including hospital beds, medications, and personal protective equipment (PPE).

The risk potential for patient surge and healthcare professionals contracting the disease have strained healthcare systems across the globe. For instance, approximately 10% of Lombardy, Italy's doctors and nurses could not report to work in early March because they had either contracted COVID-19 or were in quarantine due to close contact with an infected individual (Winfield and Barry 2020) In addition to shortages in personnel, medical resources including PPE were in short supply during the start of the pandemic. PPE shortages led some doctors in strained healthcare systems such as Brooklyn, New York, to re-use masks for over a week, reducing mask efficacy to protect clinicians, staff, and patients (Ramachandran et al. 2020; Fink 2020). Further, the availability and allocation of intensive care unit (ICU) beds has been demonstrated to be a key determinant in patient outcomes (Arango 2020). Heavily impacted cities faced shortages in ICU bed availability based on the *status quo* healthcare system, necessitating the need to quickly and equitably increase bed availability. For instance, in Madrid, Spain, the number of ICU beds made available increased sevenfold in the first few weeks of the COVID-19 pandemic (Arango 2020). To effectively and simultaneously plan and respond to this emergent threat in real-time, healthcare and other first responder organizations had to consider the potential for COVID-19 surges and how this would impact their organizational capacity and decision-making.

This urgency is particularly salient for emergency response in austere or remote locations with limited capacity for rapid assistance from well-resourced regions. Despite progress towards modernization and innovation in hospital system management, many underserved or remote regions have limited reserve capacity (Arifin 2017), or are not able to consistently delivery emergency and crisis response healthcare consistent with international standards and best practices (Phillips et al. 2020). Among others, examples include smaller island territories and nations, rural areas with no major national/international airport, and areas vulnerable to climate extremes. Within such contexts, hospital systems remain highly utilized in a steady-state environment, where the burdens of care delivery (acute and chronic care) push utilization rates (i.e., the proportion of routine service beds or intensive care beds in regular use) well above 50%–and occasionally above 75%. This utilization rate trend, coupled with the limited aggregate availability of such resources (rates of resource availability proportionate to the population in such regions are quite unfavorable), leaves austere and remote environments easily overwhelmed by sudden intake of patients as with a pandemic. In such environments, a lack of reserve capacity and overall resilience within the public health system may contribute to situations requiring triage—likely generating harmful health consequences where those otherwise qualifying for care are not able to receive it in a timely and consistent fashion.

This chapter describes a framework to better understand the preparedness of a given public health system for a potential pandemic outbreak—accounting for infrastructural, population health, and epidemiological challenges unique to a given area. Though the discussion described herein can be applied to any jurisdiction, this chapter explicitly focuses upon austere and remote environments that have unique challenges related to limited pre-pandemic resilience capacity. Specifically, we review the U.S. Territorial Islands in the Pacific Ocean, inclusive of Guam and the Commonwealth of the Northern Marianas Islands (CNMI). Based on the evolving data availability and socio-political considerations, this real-time anticipatory response recommends not just a singular headstrong plan, but rather an anticipatory, proactive approach that integrates updated information to ensure actions remain on target towards diminishing the threat.

Our study of organizational healthcare resilience considered epidemiological models, public health, and healthcare infrastructure. To do so, our real-time anticipatory response method assess COVID-19 transmission potential and healthcare system resource capacity planning and building. The method integrated empirical information using existing public data sources, as well as key stakeholder feedback. Given the initial uncertainty at the start of the pandemic—met with the need for healthcare systems to prepare and respond in some way—it was essential to develop a model that would be updated and reiterated based on emerging empirical data as well as multidisciplinary stakeholder feedback.

4.2 Theoretical Context: Defining the Field of Organizational Resilience

Organizational resilience has been posited as a theory to facilitate and encourage organizational preparation for, ability to cope with, and ability to recover from adverse events and crises that cause organizational disruption (Rangachari and Woods 2020). Crises can generally be defined as "…a significant threat to operations that can have negative consequences if not handled properly" (Coombs 2007, pg. 1). Crises can present a variety of threats, including those that bear adverse consequences for public safety, financial security, and organizational reputation.

These and other threats incur potential damage to the organization and its stakeholders (Coombs 2007). As defined here, crisis can take the form of pandemics (the focus of this chapter), natural disasters, and economic collapse, among others.

Organizational resilience in the face of such crises can be considered a subset of engineering resilience, which Holling (1996) defines as the ability of a system or organization to maintain efficiency of function despite disturbance. Most other definitions of engineering resilience and organizational resilience touch on the theme of a phasic approach to planning and preparing for, absorbing, recovering from, and adapting to adverse events, considering short- and long-term planning and investments of time and resources (National Research Council 2012). For instance, Rangachari and Woods (2020) argue that organizational resilience is exemplified through three phases: (i) foresight, (ii) coping, and (iii) recovery (Rangachari and Woods 2020). Similarly, Coombs (2007) defines effective crisis management shaping organizational resilience in terms of (i) pre-crisis prevention and preparation, (ii) crisis response, (iii) post-crisis functioning and adaption. The notion of planning and preparing for foreseeable shocks and stresses is common across all definitions of resilience. Accordingly, this chapter discusses a method that aimed to enhance healthcare systems' ability to prepare for and respond to pandemic crises, such that healthcare systems can prepare for and respond to potential patient surges. The models developed in this chapter enhanced preparation and response efforts through estimating whether medical personnel and resource capacity on each island could meet the potential needs of patients should COVID-19 hospitalization surges occur.

According to Wildavsky (1991), Vogus and Sutcliffe (2007), resilient organizations must improve their overall capability to assess, learn from, and act upon adverse events, "without knowing what one will be called to act upon" (Wildavsky 1991, pg. 70). Though definitions of resilience in different domains provide slightly different names for the components of organizational resilience, most conceptualizations of resilience are phasic (e.g., preparation, response, recovery, adaption). According Rangachari and Woods (2020), organizational resilience is manifested across three interconnected levels: (i) the individual level, (ii) the team level, and (iii) the organizational level. Rangachari and Woods (2020) argue, "…if resilience is restructured to individual level without advancing to the team and organizational levels, it could leave the organization suspended in a reactive or brittle stage of resilience (as opposed to proactive or full resilience)" (pg. 3). As such, the current approach was geared at the organizational level, while integrating feedback from individual stakeholders and key decision-makers who work directly within these organizations or systems to help reduce uncertainty or misinformation that might be published to the public.

When organizational decision-making must occur in real-time due to the swiftly unfolding nature of many crises, organizations and their key decision-makers are often left with limited time or information to sufficiently prepare for crises (Lengnick-Hall 2011). This forces organizations to base early-intervention decisions on incomplete, unconfirmed, or potentially erroneous misinformation. Learned information about modes of transmission, as well as behavioral interventions to mitigate transmission, can and should be incorporated into models of disease spread to provide an updated, iterative, and behaviorally-realistic assessment towards real-time anticipatory response.

Despite misinformation or information paucity, organizational decision-makers must act to support the organization, which in turn often supports the larger community. Under pandemic and other disaster or crisis conditions such as natural disasters or industrial accidents, healthcare systems are at the core of public health and safety. Healthcare, public health, other first response organizations are uniquely positioned in that they must provide both immediate response and support for the larger communities they serve that face disruption, while concurrently balancing their own internal organizational needs. These needs include ensuring an adequate supply of professional healthcare personnel and medical resources necessary to equitably handle and care for patients and staff. The ability to manage healthcare professionals and resources as well as treat patients during a large-scale crisis is vital as failures can "…result in serious harm to stakeholders, losses for an organization, or end its very existence." (Coombs 2007, pg. 1). Accordingly, healthcare organizational resilience has been defined as, "… the ability to improvise with materials at hand and develop solutions to unexpected problems, thereby enabling patient care to be delivered safely despite obstacles" (Rangachari and Woods 2020, pg. 3).

Considering that many crises entail considerable uncertainty and misinformation, Vogus and Sutcliffe (2007) discuss the necessity for organizations to monitor and simulate their environment under various scenarios and potential futures to improve the organization's ability to detect and prepare for disruption. Building upon Vogus and Sutcliffe's conceptualization of iterative and flexible organizational resilience, we apply real-time anticipatory response as a means of real-time organizational risk assessment, modeling, preparation, and capacity building under unforeseen, disruptive external events and pressures.

Some unpredicted or novel crises that require swift response necessitate a real-time feedback loop between planning/preparation and response. Accordingly, we define real-time anticipatory response as the early monitoring and planning for an unforeseen or novel threat or crisis as it unfolds and for which an immediate response is necessary to minimize potential damage. Real-time anticipatory response involves estimating or modeling potential futures under a variety of scenarios and promotes iterative modeling efforts and flexible organizational response in order to adjust for the uncertainties in the threat or crisis. In cases where immediate action is necessary but there is little time for sufficient planning, collaboration, and feedback from a diverse set of stakeholders can help to swiftly inform organizational leaders and lessen immediate uncertainties. Despite the global scale of some crises, including the COVID-19 pandemic, regional approaches can better take into account the affected population and involve regional stakeholders, allowing data to be tailored towards improved modeling accuracy and decision-making which can provide better safeguards to sustain life and prevent negative outcomes.

Real-time anticipatory response can position key decision-makers in regional organizations towards a path for a faster pandemic response and, ultimately, a speedier recovery. According to Iserson (2020a), "[p]roviding the best current information about the risks as well as the opportunities to assist during a crisis will help healthcare provider professionals make defensible decisions in disaster settings" (pg. 478). Therefore, the "real-time anticipatory response" framework and method that we introduce promotes the estimation and communication of iterative reports of potential damage and resource requirements based on available data and stakeholder feedback. This approach pushes for transparent information distribution that clearly identifies key sources of uncertainty that can be informed and updated through both experience and advancements in empirical research and data.

By identifying sources of uncertainty, research agendas can be prioritized to improve modeling capabilities. Through prioritized collection of new data as an initial outcome of uncertainty identification, or by updating models as additional third-party information becomes available, it is possible to develop a reasonable risk assessment while simultaneously generating collaboration and trust between researchers, analysts, healthcare organizations, and the regional population impacted during conditions of extreme uncertainty. In the context of novel pandemics, physicians and other key healthcare decision makers need to consider how to distribute available resources (i.e., test kits, personal protective equipment (PPE), hospital rooms and beds, ventilators, etc.) and obtain or improvise others. The models developed here aimed to facilitate risk assessment and decision support in real-time to aid island healthcare system strategy development for the allocation of scarce resources, as well as contingency planning should their organizational capacity be overwhelmed.

4.3 Real-time Anticipatory Response to COVID-19

Under pandemic and other disaster or crisis conditions, healthcare systems are at the core of public health and safety, thus, it is necessary to foster and maintain organizational resilience within healthcare providers and networks of providers, especially during times of significant organizational strain (Rangachari and Woods 2020). As the COVID-19 crisis initially unfolded, the information environment from which organizations could base decisions was plagued by uncertain data and misinformation. Healthcare providers and public health policy makers needed to engage in "real-time anticipatory responses" that sought to treat those stricken by the disease while also communicating widely within communities about their concerns and how to stop the virus from spreading.

During the first lifecycle phase of the crisis (i.e., an incubation period with high uncertainty; Fig. 4.1), estimates of COVID-19 transmission, hospitalization, intensive care unit (ICU) admissions, and fatality rates were critical in informing decision-making in the second lifecycle phase when time-sensitive decisions, such as medical resource allocation became critical. As the United States faced a medical

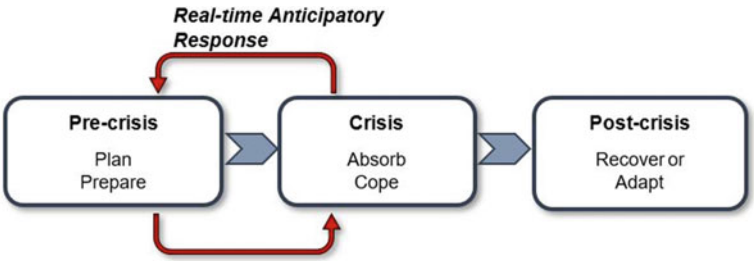

Fig. 4.1 The crisis management lifecycle as conceptualized by Coombs (2007) and how organizational resilience phases map onto the crisis lifecycle. For rapidly unfolding, unanticipated events, real-time anticipatory response is an iterative process between planning, preparing, absorbing and coping from the event. This iterative feedback loop is particularly useful when uncertainty is high; initial models of potential scenarios inform planning and preparation and are continually updated and informed by realized experiences and gained empirical data to fine-tune and steer ongoing intervention processes

resource supply shortage (Kamerow 2020), it was imperative that medical resources were distributed equitably while also considering where and when risks would be greatest. While epidemiological models are used in such capacities to help regional and national resource allocation, they often include various sources of uncertainty and generalized assumptions that prevent regionally-adjusted outcome projections. For instance, at the time, the transmission and hospitalization rates of COVID-19 were unknown and hospitalization needs were uniformly distributed across the population. Moreover, early research showed that socio-demographic characteristics and pre-existing health conditions indicated trends of who could be most susceptible to COVID-19 infection and suffer more severe outcomes (Chow et al. 2020; Clark et al. 2020).

This chapter focuses on a methodological approach that was developed to facilitate real-time anticipatory response to COVID-19 for healthcare systems on several Pacific U.S. Territory Islands. Despite rampant scientific uncertainty and misinformation, those engaged with crisis response are still required to deliver upon their mission. Our team supported multiple U.S. Territory Island jurisdictions in their healthcare systems' anticipatory response to the COVID-19 pandemic. Through this action-based research, we developed a multidisciplinary approach to diminish some of the uncertainty around the virus and provide empirically backed recommendations to policy decision-makers regarding response options, particularly in allocating resources to areas of imminent need.

Existing epidemiological models formed the backbone of our analyses and model projections, which showed worst, best, and most likely outcomes for the regions of study. Our model addressed gaps in existing emergency epidemic modeling and could be contextualized to specific regions through: (i) current COVID-19 case counts and growth rates, (ii) publicly available demographic and public health data on population pyramids and comorbidity rates, and (iii) current hospital and healthcare system equipment provisions and utilization rates. The goal of this work was to identify the inflection points for which COVID-19 caseloads would exceed and potentially overwhelm the healthcare infrastructure available on various U.S. Territory Islands based on the current healthcare infrastructure and personnel in place. Model of potential caseloads were intended to aid risk assessment and decision support for regional healthcare workers and public policy makers, who ultimately decided their resource constraints, needs, and public policy standards and regulations.

4.3.1 Managing Initial Obstacles and Uncertainties

The COVID-19 response was mired with uncertainty in its early weeks. Between February and March 2020, the relative rate of transmission, as well as the severity of its consequences were only partially observed and sampled, with new information arriving each day regarding new challenges or requirements. Two fundamental obstacles arose during the initial pandemic crisis response: misinformation and uncertainty. One of the most plaguing characteristics of early response to novel issues like this one is rampant reporting of misleading and even fictitious information in response to valid questions from stakeholders and the public. The global involvement and ubiquity of digital media increased the visibility and discussion of various forms of misinformation regarding COVID-19 to the point that a recent six-country study found that roughly one third of social media users confronted false or misleading COVID-19 information online (Nielsen et al. 2020). Low-barrier access to the internet provides opportunities for information-seeking, as well as greater exposure to false information (Cummings and Kong 2020). During this early period of disease spread, misleading information on COVID-19 took various forms that ranged from accidental or erroneous misinformation to more maliciously intended disinformation created to purposefully mislead readers (Vériter et al. 2020; Sharma et al. 2020). Rumors that sought to provide plausible rationales and realities during this highly uncertain period became doubly difficult to counteract as they obfuscated the truth. Rumors gain gravitas because they serve as a mechanism of communication and persuasion constituted by “a source of information that is not controlled by the powers that be” (Kapferer 1990, p. 7). The inability to confirm the veracity of early response information is a serious hindrance to an effective and immediate response, drastically lowering the confidence of decision-makers and stalling adequate mitigation strategies and initiatives. This strains organizations to make life-or-death decisions mired by what little valid information is available. This may force organizational decision-makers to enact trust heuristics to gauge the veracity of information available often based on the tradeoffs between the source and the substance of the information. Judging which information to trust, when, and for what purpose is of paramount concern and greatly hinders adequate early organizational response.

Emergency management should include the entire lifecycle of crises to diminish threats of cascading disruptions caused by failures to anticipate the situation’s evolution over time (Coombs 2007). Researchers have modeled this lifecycle in three stages: (1) there is a pre-crisis incubation period marked by extremely high uncertainty and a series of warning signals, (2) the crisis event, marked by instability where time-sensitive decisions are crucial, and (3) a post-crisis phase where immediate safety is restored and community learning mechanisms are initiated (Coombs 2007). As noted by Laugé and colleagues, "…effective crisis management starts well in advance of the actual physical manifestation of the crisis" (2009). However, it is difficult to determine the difference between true-to-life precursor events and crisis warnings during the pre-crisis phase. Little guidance or formal rubrics for signal detection exist, allowing many warnings to go unnoticed, undervalued, or perceived as unrelated events (Laugé et al. 2009).

4.3.2 Pacific Island Vulnerabilities

This application of "real-time anticipatory response" for healthcare systems as they face potential COVID-19 transmission and outbreaks focused on U.S. Territory Islands in the Pacific Ocean. These islands are home to communities that may be particularly vulnerable to COVID-19 illness and implications. According to Phillips et al. (2020), Pacific Island countries and territories "…share a substantial burden of environmental, climatic, and communicable disease threats and can work collaboratively to address regional health priorities that are locally identified, evidence-based, and Pacific context-relevant" (pg. 2). Notably, inhabitants of Pacific Island countries and territories show higher average rates of chronic diseases, such as heart disease and diabetes, relative to the contiguous U.S. average rates. For instance, in 2018, Native Pacific Islanders/Hawaiians were 2.5 times more likely to be diagnosed with diabetes and 10% more likely to be diagnosed with coronary heart disease relative to the non-Hispanic white population (U.S. Department of Health and Human Services 2019a, b). As these and other underlying health conditions, also referred to as comorbidities, are associated with increased COVID-19 case severity (Auwaerter 2020), Pacific Island countries and territories were considered more at-risk for COVID-19 related hospitalization than other regions with lower comorbidity rates across the population.

Further, Pacific Island countries and territories are particularly vulnerable to tropical cyclones and flooding (Phillips et al. 2020). Moreover, inhabitants of these islands are more physically removed from each other and generally have fewer healthcare facility options. Therefore, it is more challenging to mobilize and respond immediately to crises, as considerable travel distances are required (Iserson 2020b).

Pacific Islands also have unique cultural and social considerations that may be less apparent to those less familiar with the islands or unavailable via online resources. Stakeholder communication was critical in understanding these factors. To develop and inform sound "real-time anticipatory response" based on overcoming potential barriers in uncertain data and misinformation, there was a need to build trust between interdisciplinary stakeholders, including the research and modeling team, healthcare professionals, and public health policy makers. Like in Phillips et al.'s (2020) work on Pacific Island healthcare systems, our work involved direct, iterative communication to better understand the local and unique needs of the U.S. Territory Islands studied. The needs pertained to their healthcare infrastructure, public health and comorbidity rates, and cultural consideration. For example, through these conversations we learned that many of the U.S. Territory Islands have more multigenerational households than the contiguous United States—information that was empirically supported through U.S. Census Bureau data (2010). This cultural consideration was important to recognize because multigenerational households may carry added COVID-19 transmission risks, as older generations are exposed to younger generations, who may attend work and/or school and face greater infection risks while remaining asymptomatic.

Additionally, while public safety should be prioritized in healthcare management and decision-making, crises can also threaten financial loss and reputation (Coombs 2007). These three sectors (public safety, financial loss, and reputation) are interrelated. The health of a community influences the ability for community members to attend work and generate income, especially for tourism-based economies. Community health is closely related to how potential tourists might perceive and decide to travel to destinations (i.e., less appealing due to legal restrictions on visiting). Many Pacific Islands have tourism-based economies. For example, 17.8% of Guam's 2016 gross domestic product (GDP) was derived from tourism. Additionally, the tourism industry in the Northern Mariana Islands employs approximately 50% of the total work force and accounts for roughly one-fourth of the island's GDP (United States Central Intelligence Agency 2019a, b). Further, Pacific Island countries and territories tend to have higher rates of people living in poverty than the contiguous United States. According to U.S. Census Bureau, Guam, the Northern Mariana Islands, the U.S. Virgin Islands, American Samoa, and Puerto Rico each had poverty rates higher than all contiguous U.S. states (U.S. Census Bureau 2010). High poverty rates may stress populations effected by the COVID-19 pandemic, potentially making preventative personal health measures and adequate treatment less accessible.

4.3.3 Developing a Multidisciplinary Approach Through Various Data Sources and Stakeholder Input

To improve decision-making during the novel coronavirus pandemic, accurate, up-to-date data are critical to combat misinformation and uncertainty. For any epidemiological model to be valid it requires accurate COVID-19 case, hospitalization, and fatality rates over time. During the initial stages of a pandemic, accurate data pertaining to COVID-19 case and severity rates were difficult to acquire for many reasons including that frontline workers were left to scramble in immediate crisis response which detracts from time and human resources to adequately document data as they emerge. Further compounding this dearth of information was the limited early testing capabilities, the shortage of contact-tracers, public awareness of signs and symptoms of the disease was low, and many asymptomatic individuals were often unaware that they could actively spread the virus to others. To overcome these challenges, we collected data from multidisciplinary sources, including the U. S. Census Bureau, various public health resources for underlying illness rates, and expert judgement from those working directly within the healthcare and/or public health systems on U.S. Territory Islands. Current COVID-19 case counts, and growth rates are published directly by local, state, and federal governments, generally down to the zip code- or county-level. Our analyses focused on the state/territory level.

From a clinical perspective, risk factors for developing severe health outcomes post infection were still not fully known or validated. Disease transmission rates were not confirmed and clinical guidelines for how to treat COVID-19 patients and for how to protect against disease spread to healthcare professionals changed daily. Last, there were massive coordination challenges in collecting accurate data on supply of medical equipment, burn rates for personal protective equipment, and the number of surge hospital beds needed, as few health systems actively tracked their supply and demand. For example, surgical masks and gloves were often treated as disposable goods similar to toilet paper and paper towels. They were purchased in bulk when supplies seemed to be running low, but actual quantities were rarely tracked.

Our model used publicly available demographic and public health data on population pyramids and comorbidity rates. The data that we used came from the United States Census Bureau (for data on population distributions) and the Centers for Disease Control's Behavioral Risk Factor Surveillance System (for age-adjusted, state-specific disease prevalence data for the noninstitutionalized, U.S. adult population). Synthesizing this information allowed us better to understand varying regional risks in U.S. states and U.S. territories and is detailed in the ensuing section of this chapter.

Current hospital and healthcare system equipment provisions and utilizations rates were found either directly through hospital systems or through third-party

Table 4.1 Available civilian routine and ICU beds, including non-COVID utilization rates for Guam according to the American Hospital Directory

	# Routine service beds	# Special care beds/ICU	Utilization rate (non-COVID conditions) (%)
Guam Memorial Hospital	147	14	85
Guam Regional Medical City	88	17	55
Total	235	31	

sources such as the American Hospital Directory (AHD). Data pulled from the AHD included: (a) how many hospitals or acute care facilities exist on the ground at present, (b) how many routine service beds and ICUs are available across all facilities, (c) counts of PPE and mechanical ventilators, and (d) available personnel (doctors, nurses, technicians, and staff). Table 4.1 shows an example of these AHD estimates; it is important to note that these estimates may entail some degree of uncertainty if the information is not updated regularly or misreported. As such, our team has directly communicated via conference calls with hospital directors, physicians, and public health directors in certain regions of study in order to learn more about the region's status quo regarding the healthcare system, COVID-related expansions, and medical equipment, personal protective equipment and healthcare personnel needs. These multidisciplinary communications have served to update our estimates of hospital information that is online and outdated or missing (i.e. PPE utilization). These direct lines of communication have also demonstrated to us the value in multidisciplinary communications. The hospital and public health representatives that we communicated with were interested in filling in uncertainties in data to improve and make more accurate model estimates. Ultimately, these estimates helped determine the allocation of needed medical resources to a region. These estimates are particularly pertinent in regions such as U.S. territory islands, for which the medical supply chain is more complex, and outsourcing is not easily possible. A critical consideration includes the Utilization Rate (also known as the 'Hospital Occupancy Rate'). This accounts for the number of beds, resources, and staff required to treat non-COVID patients based upon general averages prior to the pandemic. This number may reduce due to the cancellation of elective surgeries and non-emergency health conditions. However, it should not be assumed that all beds, PPE, ventilators, and staff are available to treat COVID—some must be on hand to address other emergency conditions.

Through multidisciplinary communications with hospital and public health directors, we learned about unique cultural and community characteristics that might influence COVID-19 transmission and severity. While these considerations are not presently incorporated into our models, we recognize that these factors may be influential in COVID-19 transmission. For instance, health officials in a U.S. territory posited that the territory's higher average people per household rate might influence COVID-19 transmission, such that there are generally more people living within the same household in that region than within the contiguous United States. Often, these households are multigenerational, which could also pose unique risks. Additionally, public health officials discussed how socioeconomic factors like tourism may have influenced the influx of the virus onto the island. For example, if residents do not live near these traditionally tourist-based districts, they may have lower exposure to the virus. Last, there are important social and cultural considerations that differ between regions which could impact the effectiveness of policies such as adherence to social distancing guidelines. Incorporating them into future models can help add further granularity in identifying at-risk regions.

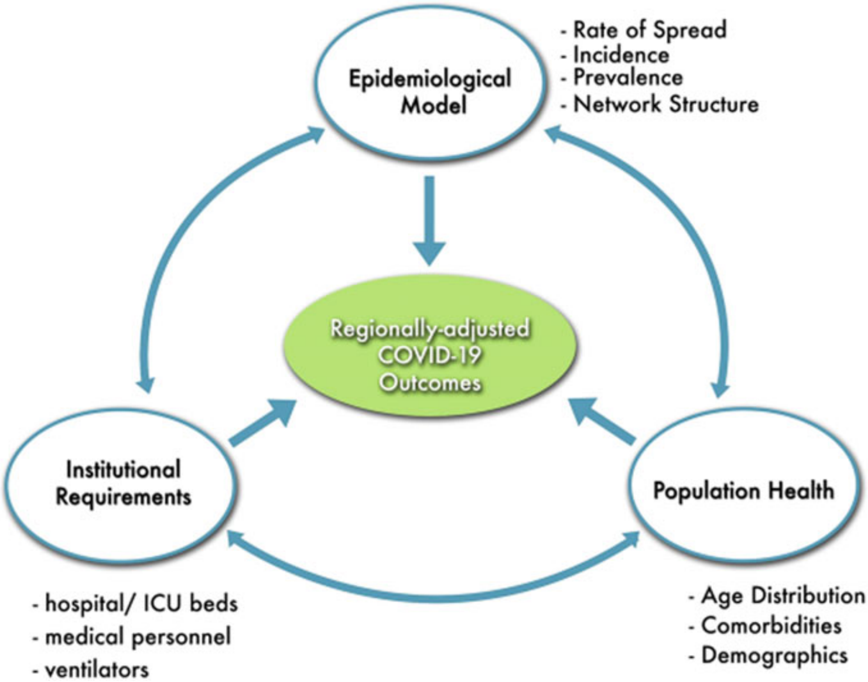

Fig. 4.2 Three-tiered approach for modeling, analyzing, and addressing COVID-19 transmission and outbreaks across defined populations

4.4 Modeling Regional Real-time Adaptive Response to COVID-19

The overall goal of our real-time adaptive response modeling approach was to identify the inflection points for which existing healthcare systems on several U.S. Territory Islands would be overburdened due to COVID-19 caseloads. These models incorporated regionally-adjusted inputs and parameters to tailor the analyses and results to specific U.S. Territory Islands. Figure 4.2 shows the three-tiered modeling approach that we developed to do so, which incorporated the data outlined in Sect. 3. *Identifying and Filling Data Gaps During the COVID-19 Crisis*. To set the initial foundation of the modeling framework, traditional epidemiological models that predict disease spread where used. As COVID-19 severity has been shown to be positively correlated with age and various underlying illnesses/ comorbidities, we integrated the unique population health characteristics of specific island territories to tailor the COVID-19 case predictions based on local population characteristics (i.e., age, comorbidities). The projections were mapped to existing institutional healthcare system resource availability, including the number of hospital/intensive care unit (ICU) beds, medical personnel, and ventilators. The goal was to identify a tipping point for which the *status quo* healthcare system would be rendered inadequate due to COVID-19 patients exceeding medical resource and personnel provisions.

The first step within our approach used several necessary principles of epidemiological modeling to project how COVID-19 might spread within specific island territories. We modeled COVID-19 epidemiological spread based on three best, worst, and most probable scenarios. To model the best-case scenario (i.e., the minimal number of COVID-19 cases), we first used a Polynomial Statistical Model (Dinwoodie 2002) framework. Polynomial regression models are useful in determining which input factors drive responses, and they allow statistical analyses when there is incomplete data. This statistical model used the number of confirmed cases in each region to represent its best-case scenario and optimistic health outcome. Second, we supplemented the polynomial model with an exponential model, as it is well established that epidemics tend to grow exponentially. This second model utilized an exponential growth rate as averaged across the United States. This statistical model was used to predict the worst-case scenario in each region (i.e., more dire health outcomes). While these projections are useful, they are also notably flawed and do not account for response and variation of disease projection after only a very short early period of pandemic spread (Chowell et al. 2016).

Finally, we modeled the most probable scenario using the Susceptible, Exposed, Infected, Recovered/Removed (SEIR) modeling approach (Aron and Schwartz 1984), a widely used model of disease spread in epidemiology literature. The SEIR is a compartmental model that 'buckets' sections of a given population into one of the four categories listed in its name. SEIR models utilize known data specific to the virus and location under assessment, such that the models can reflect various policy scenarios. The SEIR model was used for long-term COVID-19 case prediction with

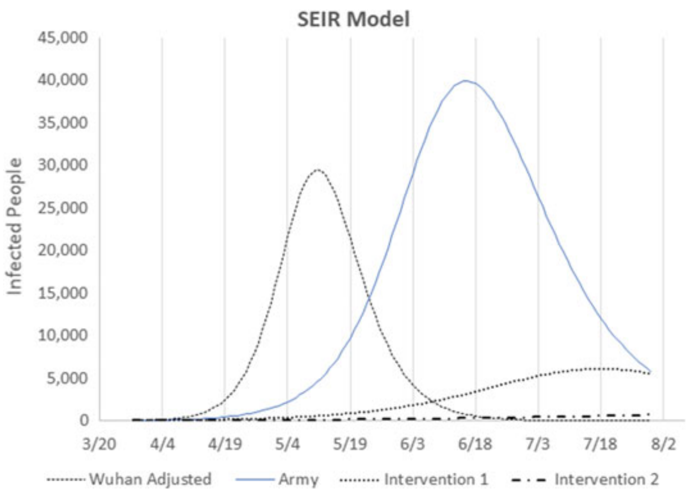

Fig. 4.3 Example of SEIR model output according to several potential transmission scenarios

parameters validated using preliminary patient outcome data from Wuhan, China—among the few patient-level data sources available in March 2020 that accounted for concerns related to age and comorbidity concerns (Kucharski et al. 2020).

Figure 4.3 shows an example of SEIR model output according to hypothetical data, in which the number of infected individuals were predicted over approximately five-months. In the current analyses, we ran the SEIR model for three scenarios for each specific U.S. Territory Island. An example of public health policy scenarios included in epidemiological modeling for U.S. Territory Islands included variations of the following: (i) no further intervention to reduce disease transmission, (ii) a reduction in disease transmission by 50% (e.g., a speculative 'shelter-in-place' order that is effectively implemented and followed), and (iii) a reduction in disease transmission by 60% (e.g., a speculative shelter-in-place and extensive testing of the island's population). The United States CDC issued guidance on the model parameter and scenarios to consider (CDC 2020a, b).

Using these three traditional epidemiological models, we developed region-specific projections. We further supplemented them with regional population health analyses. Based on the infected population data, we generated numbers of: (i) general hospitalizations, (ii) admissions to an ICU, (iii) required use of an invasive ventilator, and (iv) fatalities for each region. The following modifying factors were used: (a) the region's population pyramid, and (b) rates of identified comorbidities (e.g. heart diseases, chronic metabolic diseases, chronic respiratory diseases, cancer) that varied by region. Using time-series information generated in the epidemic model, we analyzed different possible health outcomes of COVID-19 infection per day, assuming a uniform infection rate for all age groups. While we assumed a uniform infection rate across age groups, we improved upon existing models' assumptions of uniform hospitalization, ICU, and fatality rates by incorporating each region's unique population health characteristics.

4.4.1 Population Health Analysis

After deriving an initial set of the epidemic 'curves' (or how quickly the disease spreads, as well as the maximum number of infected at a single point in time), the next step included understanding population health factors that might influence health outcomes. Certain underlying factors (e.g., age, chronic health conditions) have been described as affecting the rate at which COVID-19 cases require: (i) general hospitalizations, (ii) admissions to an ICU, (iii) required use of an invasive ventilator, and (iv) fatalities.

This population health analysis allows you to understand how COVID-19 would uniquely influence a given population. Relevant considerations include (a) the population pyramid of the location (age/sex distribution of residents), and (b) co-morbidities including cardiovascular disease, diabetes, chronic respiratory disease, hypertension, tobacco/smoking rate, and tuberculosis, among others. Table 4.2 includes an aggregation of case fatality outcomes noted by John's Hopkins

Table 4.2 Aggregated John's Hopkins University case fatality rate estimates by age and pre-existing conditions. The percentages reflect the total percentages of patients who were infected by and died due to COVID-19

Age	Case fatality rate (%)	Pre-existing condition	Case fatality rate (%)
80+	14.8	Cardiovascular disease	10.5
70–79	8.0	Diabetes	7.3
60–69	3.6	Chronic respiratory disease	6.3
50–59	1.3	Hypertension	6.0
40–49	0.4	Cancer	5.6
30–39	0.2	No pre-existing condition	0.9
20–29	0.2		
10–19	0.2		
0–9	None		

University, which was a critical early reference point for population health outcomes for COVID-19. Data published by Johns Hopkins University (JHU) indicates that underlying comorbidities, along with advanced age, are causally linked to more severe health outcomes for those infected with COVID-19 (Auwaerter 2020). Joining JHU's rates of COVID-19 severity by comorbidity with each region's specific comorbidity prevalence, we have developed region-specific model projections to better reflect variance in regional population health contexts. The comorbidities that were included in our models were prevalent non-communicable diseases, such as chronic metabolic diseases (i.e. diabetes, kidney disease, obesity), chronic cardiovascular diseases (coronary heart disease, stroke, heart attack, hypertension), chronic pulmonary diseases (COPD, asthma), and cancer. These comorbidities, along with how they are distributed across age groups at the state level, were used to inform predictions of hospitalization rates, ICU rates, and fatality estimates over time for each given region.

4.4.2 Organizational Resource Requirements

After understanding the rate and timeline of epidemic spread (Step 1) as well as a region's demographics and health conditions that influence the rate of severe health outcomes (Step 2), the final step was to review available organizational and healthcare infrastructural resources. To do so, we addressed two critical factors in healthcare organizational resilience and real-time anticipatory response, including (i) the timeline when available resources will be exceeded, and (ii) the timeline and magnitude of resource requirements at a 'peak' in the COVID curve. By comparing available resources and predicted needs, we can estimate the time when demand exceeds resource availability. This included (a) how many hospitals or acute care facilities exist on the ground at present, (b) how many routine service beds and

Table 4.3 Prediction for resource needs under baseline and two different policy interventions. Available Service Beds refers to routine hospitalization, while ICU Beds refers to those requiring more extensive care and likely an mechanical ventilator

		Available service beds	Available ICU beds	Exceed available service beds	Exceed available ICU beds	Peak date	Needed service beds at peak	Needed ICU beds at peak
SEIR	No intervention	62	10	4/9/2020	4/5/2020	5/11/2020	5,893	1,473
SEIR	50% reduction	62	10	4/29/2020	4/21/2020	7/18/2020	1,227	307
SEIR	60% reduction	62	10	6/13/2020	5/23/2020	10/12/2020	278	70

ICUs are available across all facilities, (c) counts of PPE and invasive ventilators, and (d) available personnel (doctors, nurses, technicians, and staff). A critical consideration includes the Utilization Rate (also known as the 'Hospital Occupancy Rate'). This accounts for the number of beds, resources, and staff required to treat non-COVID patients based upon general averages prior to the pandemic. While the pre-COVID-19 Utilization Rate may decrease should elective surgeries and non-emergency health conditions be postponed or cancelled, it should not be assume that all beds, PPE, ventilators, and staff are available to treat COVID-19 patients. Some healthcare professionals must be on hand to address other emergency conditions.

Table 4.3, using publicly available information, shows an example of how existing healthcare system infrastructure was compared to the COVID-19 caseload model projections in order to estimate the approximate date that the COVID-19 case, hospitalization, and ICU rate curves would exceed the *status quo* healthcare capacity on one specific island. While the exact dates were approximations that did not accurately reflect the date of peak COVID-19 caseloads for this particular, unidentified U.S. Territory Island, the rate of transmission across the curve under policy scenarios followed a trajectory that was similar to that which was realized.

4.5 Modeling Results and Interpretation

We estimate COVID-19 caseloads and potential hospitalization and ICU cases across a period of approximately six months for several U.S. Territory Islands using the three-tiered approach modeling approach outlined in this chapter. To account for uncertainty, used a several scenarios to reflect public health and regulation policies that were anticipated to reduce the rate of transmission. The output included curves for the projected COVID-19 cases that would be sufficiently severe to require medical attention and use healthcare system resources and personnel

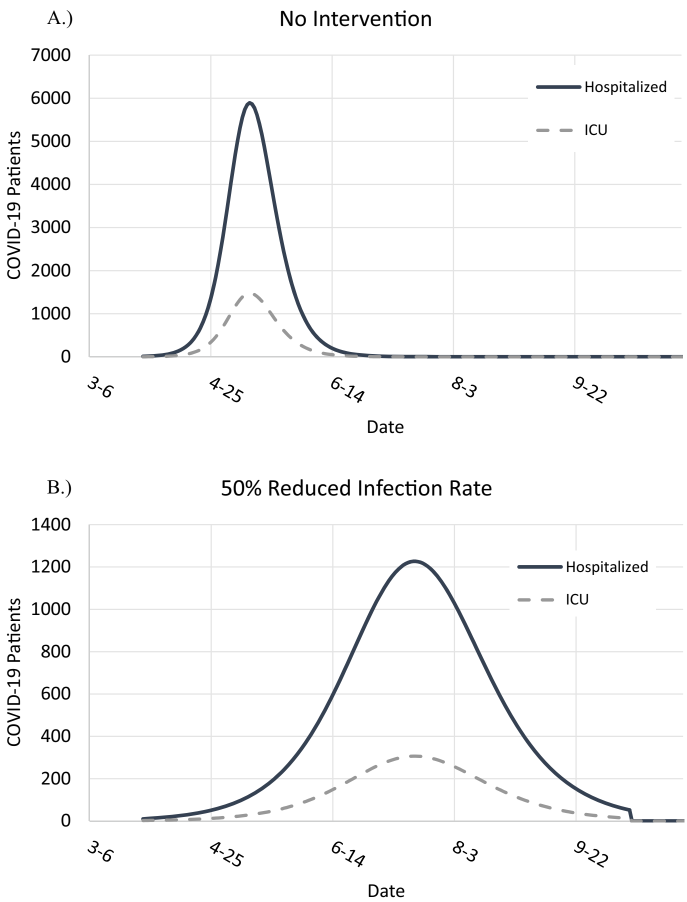

Fig. 4.4 Projected COVID-19 caseloads over time according to the SEIR model and two policy scenarios: **a** No behavioral intervention (i.e., no business closure regulations, no mandatory mask use, unrestricted size of social gatherings) and **b** estimated 50% reduction in infection rate based on instantiation of behavioral interventions (i.e., business closure regulations, mandatory mask use, restricted size of social gatherings) that reduce public activity and reduce the number of contacts by which the disease may spread within a given area and time

(Fig. 4.4). The projected case, hospitalization, and ICU caseloads were compared to the *status quo* resource capacities of island healthcare organizations. These epidemiological outputs were compared relative to the existing healthcare system resources capacity to estimate if and when the COVID-19 hospital patient surge would exceed available infrastructure and resources. Potential surges under various policy scenarios were modeled. Policy scenarios included behavioral interventions designed to reduce COVID-19 transmission, such as the regulation for mask use while in public spaces. Through these and similar modeling efforts, it was possible to aid healthcare systems and organizational decision-makers real-time anticipatory response while considering the potential risks of COVID-19 within their island. We communicated results to healthcare organizations and key decision-makers to provide informed decision support based on real-time data and situational analysis. Based on the results and interpretations of results under uncertainty, these models better equipped healthcare organizations to call for more medical personnel and resources in advance of the potential COVID-19 projections, which exceeded existing capacity thresholds. Through providing and communicating the sources of uncertainty across the various policy scenario and modeling framework outcomes, we encouraged flexible decision-making that could be updated and adapted based on iterative modeling results as more data pertaining to COVID-19 transmission became available and updated.

Even in cases of considerable reduction in COVID-19 transmission (i.e., 'flattening the curve,'), many of the islands' civilian hospital systems were not equipped to absorb the influx of hospitalizations and severe COVID-19 cases under the modeling assumptions. Existing hospital capacity was heavily burdened and utilized with non-COVID-19 patients prior to the pandemic. Even if hospital utilization constraints were relaxed, there were too few routine service beds or ICU beds to accommodate the estimated influx of patients well before the peak of cases was estimated to arrive. We estimated this through stakeholder-provided accounts of hospital utilization rates prior to COVID-19, assuming the percentage of bed space, uniformly distributed, that was typically occupied by non-COVID-19 patients. Slight deviations from these model parameters did not substantially change forecasting of when COVID-19 would exceed an island's capacity to absorb the number of cases requiring hospitalization.

Though we generalized our results here for confidentiality purposes, our results for all of the U.S. Territory Islands under each modeling scenario showed that existing hospital capacity was moderately strained prior to the COVID-19 pandemic based on hospital bed utilization rates of non-COVID-19 patients. Even if utilization constraints were relaxed, there were too few routine service beds and virtually no ICU beds to accommodate the influx of patients. In particular, the extreme deficiency of ICU beds presents limitations under the most optimistic scenarios.

These results implied two core takeaways: (1) there was a need for healthcare organization resource support, and (2) behavioral policy scenarios did serve to flatten the curve and buy time to import the additional medical resources and support necessary to be able to contain the virus should an outbreak or surge occur.

4.6 Conclusion

Despite scientific uncertainty and wide-spread misinformation, we developed a real-time anticipatory response modeling approach that could be used by several jurisdictions within their crisis management plan. To develop a sound and regionally-adjusted real-time anticipatory response based on the information available during the onset of the COVID-19 pandemic, our multidisciplinary approach helped diminish some of the uncertainty around the virus and provided empirically-backed recommendations to policy decision-makers regarding response options, particularly in identifying and allocating resources to areas of imminent need. This approach was designed to help bolster healthcare system resilience by estimating medical resource and personnel needs due to the COVID-19 case and severity projections for vulnerable U.S. Territory Islands. Based on this information, healthcare decision-makers and public health policymakers were provided with COVID-19 caseload information over time that could help inform regulatory decision-making for communities and the healthcare teams serving them.

While traditional theories of organizational resilience stress the importance of appropriately planning for and responding to crises, some crises are so uncertain and unpredictable by nature that there is an immediate need for organizations to simultaneously plan for and respond to conditions with limited to no information. Yet, these crises conditions necessitate that some response is taken that should be based on empirical estimates as opposed to a blind guess of potential outcomes. As such, we feel that current conceptualizations of organizational resilience would benefit from the iterative, flexible approach of real-time anticipatory response. This approach acknowledges uncertainty and attempts to reduce it as much as possible through integrating multiple data sources and multidisciplinary stakeholder input. The process should be iterative in nature and used to support flexible response decisions.

While regionally-adjusted epidemiological modeling was used in this case study of healthcare resilience on U.S. Territory Islands faced with the potential of COVID-19 surges, real-time anticipatory response can be used for other types of organizations facing crises. For instance, fire agencies throughout the western United States are faced with an increasingly long and severe wildfire seasons due to drought conditions and rising temperatures (Keellings and Hernandez Ayala 2019; Marsooli et al. 2019; Steel et al. 2015). Fire managers and fire fighters face critical situations for which they must act based on limited time and information. Like healthcare organizations and systems, fire agencies must be equipped with sufficient personnel and equipment to support their intended response to disaster. Now, in conjunction with the COVID-19 pandemic, appropriately planning for and responding to the multi-hazard threat space has required fire agencies to quickly adjust *status quo* fire suppression tactics to both minimize fire damage and minimize COVID-19 transmission within crews and communities. This calls for the need to pursue real-time anticipatory response, such that organizational management and resilience is informed through iterative modeling of potential fire behavior scenarios, accounting for real-time data such as COVID-19 transmission with crews. Now met with COVID-19 transmission potential within organizations and within evacuation shelters, emergency management agencies are tasked with taking immediate action based on limited information on the tradeoffs between evacuation shelters and COVID-19 transmission.

Facing such conditions, it is critical for organizations to make immediate yet informed decisions despite uncertainty. We recommend that researchers and analysts consult with pertinent stakeholders to help inform otherwise unavailable or uncertain information and use scenario analysis to provide a range of potential future outcomes. While modeling approaches need not be epidemiological depending on the crisis presented, the information and outcomes should provide decision support for organizations, and sources of uncertainty should be clearly articulated and updated as necessary. Through modeling potential futures, organizational resilience will be bolstered through enhancing and anticipating organizational preparation and response, which should be flexible. In other words, resilient organizations assume their risk assessment models are flexible and require regular updating based on learned information and evolving situations. There will always be some degree of uncertainty, and notions of "safe operations" are fragile (Vogus and Sutcliffe 2007). This call for flexible, real-time anticipatory response can help organizations realize that they should consider and pursue more than one specific response or adaptation when facing a crisis with uncertainty (Vogus and Sutcliffe 2007). This will allow for the activation, repurposing, or recombination of resources as a crisis arises and evolves (Vogus and Sutcliffe 2007).

While true mitigation of a pandemic like COVID-19 will likely only be feasible through vaccines, improved treatments, and rapid testing, a real-time anticipatory response approach that integrates multidisciplinary datapoints can help stem the tide and foster healthcare system resilience. Our regionally-adjusted pandemic assessment methodology allowed key decision-makers to make faster policy decisions about how to limit the spread of the novel coronavirus and how to respond to or plan for a crisis. While such interdisciplinary efforts can provide swift and valuable empirical data from which risk mitigation decisions can be made, larger scientific, institutional, and personal challenges remain. There is a warranted need for improved problem-based focus, multi-disciplinary, and integrated systems-thinking to innovate and respond to emerging crises like COVID-19.

A significant impediment to early COVID-19 response included the fragmentation of critical data related to disease outcomes. In crisis response, there is a limited availability of time, resources, and human energy to provide the best guidance possible before critical deadlines like policy briefings or delivering technical status updates to decision makers. Overcoming these challenges can allow regions to respond faster to emergencies and recover sooner, limiting fatalities and economic damages.

All estimates here are based upon COVID-19 parameters that are still uncertain as of this writing (November 2020). Political and institutional responses may shift the shape and nature of COVID-19 infection, hospitalization, and fatality curves. In communicating the estimated risks with relevant healthcare and public health stakeholders, we considered cultural practices unique to U.S. Territory Islands that may have limited or exacerbated the spread of COVID-19, as well as the prevalence of certain comorbidities and age demographics that may yielded severe health outcomes (hospitalization, ICU, and invasive ventilation) at greater rates than would be observed in the contiguous United States. Many of the Territory Islands studied had populations with higher prevalent rates of hypertension, asthma, obesity, diabetes, and smoking than in the contiguous United States, which was critical to integrate as comorbidities and risky health behaviors are correlated to more severe COVID-19 outcomes. Additionally, certain cultural considerations unique to the U.S. Territory Islands could have increased the potential for COVID-19 exposure, such as higher multi-generational household rates. Within multi-generational householders, children live and interact with potentially more at-risk individuals, such as their grandparents or other older family and household members. These considerations were reported along with the modeling results in order to communicate the unique risks that U.S. Territory Island communities may have faced through the COVID-19 pandemic.

Despite uncertainty, there are contexts in which organizations and teams need to rapidly respond to crises with limited information. While we minimized uncertainty in COVID-19 patient surge for healthcare systems in the U.S. Territory Islands, the general framework is based on iterative modeling and analyses that incorporate and update model parameters to simultaneously help plan for and respond to a crises in regionally-specific areas. Researchers and analysts can support key decision-makers as they actively engage with and respond to crises through integrating the organization and the larger population's unique dynamics and cultural considerations into modeling efforts.

Disclaimer: The views and opinions expressed in this article are those of the individual authors and not those of the U.S. Army or other sponsor organizations.

References

American Hospital Directory. Identification and characteristics. https://www.ahd.com/

Arango C (2020) Lessons learned from the coronavirus health crisis in Madrid, Spain: how COVID-19 has changed our lives in the last 2 weeks. Biol Psychiatry. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7141703/

Arifin B (2017) The impact of public hospital availability in underdeveloped areas on medical care utilization and household health expenditures. In: Proceedings. Annual conference on taxation and minutes of the annual meeting of the national tax association, vol 110. National Tax Association, pp 1–88

Aron J, Schwartz I (1984) Seasonality and period-doubling bifurcations in an epidemic model. J Theor Biol 110:665–679

Auwaerter P (2020) Johns Hopkins ABX Guide: Coronavirus COVID-19 (SARS-CoV-2). https://www.hopkinsguides.com/hopkins/view/Johns_Hopkins_ABX_Guide/540747/all/Coronavirus_COVID_19__SARS_CoV_2_

Centers for Disease Control and Prevention (2020a) CDC updates COVID-19 transmission webpage to clarify information about types of spread. https://www.cdc.gov/media/releases/2020/s0522-cdc-updates-covid-transmission.html

Centers for Disease Control and Prevention (2020b) COVID-19 pandemic planning scenarios. https://www.cdc.gov/coronavirus/2019-ncov/hcp/planning-scenarios.html

Chow N, Fleming-Dutra K, Gierke R, Hall A, Hughes M, Pilishvili T, Ritchey M, Roguski K, Skoff T, Ussery E (2020) Preliminary estimates of the prevalence of selected underlying health conditions among patients with Coronavirus disease 2019—United States, February 12–March 28, 2020. Morbidity and Mortality Weekly Report

Chowell G, Sattenspiel L, Bansal S, Viboud C (2016) Mathematical models to characterize early epidemic growth: a review. Phys Life Rev 18:66–97

Clark A, Jit M, Warren-Gash C, Guthrie B, Wang HH, Mercer SW, Sanderson C, McKee M, Troeger, C, Ong KL, Checchi F (2020) Global, regional, and national estimates of the

population at increased risk of severe COVID-19 due to underlying health conditions in 2020: a modelling study. The Lancet Global Health 8(8): e1003–e1017
Coombs WT (2007) Crisis management and communications. Inst Public Relations 4(5):6
Cummings C, Kong KY (2020) Breaking down "Fake News": differences between misinformation, disinformation, rumors, and propaganda. In: Linkov I, Trump BD, Roslycky L (eds) Risk and resilience for hybrid threats. NATO Science for Peace and Security Programme. IOS, pp 188–204
Dinwoodie IH (2002) Algebraic methods for polynomial statistical models. Stat Comput 12:307–314. https://doi-org.prox.lib.ncsu.edu/https://doi.org/10.1023/A:1020775726595
Fink S (2020) 'We're in disaster mode': Courage inside a Brooklyn hospital confronting coronavirus. The New York Times. https://www.nytimes.com/2020/03/26/nyregion/coronavirus-brooklyn-hospital.html
Holling CS (1996) Engineering resilience versus ecological resilience. In: Schulze PC (ed) Engineering with ecological constraints. National Academy Press, Washing, D.C.
Iserson KV (2020a) Healthcare ethics during a pandemic. Western J Emerg Med 21(3):477
Iserson KV (2020b) Augmenting the disaster healthcare workforce. Western J Emerg Med 21 (3):490
Kamerow D (2020) Covid-19: the crisis of personal protective equipment in the US. BMJ 369
Kapferer J (1990) Rumors: uses, interpretations and images, Transactions, New Brunswick
Keellings D, Hernández Ayala JJ (2019) Extreme rainfall associated with Hurricane Maria over Puerto Rico and its connections to climate variability and change. Geophys Res Lett 46 (5):2964–2973
Kucharski AJ, Russell TW, Diamond C, Liu Y, Edmunds J, Funk S, Eggo RM, Sun F, Jit M, Munday JD, Davies N (2020) Early dynamics of transmission and control of COVID-19: a mathematical modelling study. The Lancet Infect Dis
Laugé A, Sarriegi JM, Torres JM (2009) The dynamics of crisis lifecycle for emergency management. In: The 27th international conference of the system dynamics society. Albuquerque, New Mexico, USA
Lengnick-Hall CA, Beck TE, Lengnick-Hall ML (2011) Developing a capacity for organizational resilience through strategic human resource management. Hum Resour Manag Rev 21(3):243–255
Marsooli R, Lin N, Emanuel K, Feng K (2019) Climate change exacerbates hurricane flood hazards along US Atlantic and Gulf Coasts in spatially varying patterns. Nat Commun 10(1):1–9
National Research Council (2012) Disaster resilience: a national imperative. https://www.nap.edu/read/13457/chapter/1#ii
Nielsen R, Fletcher R, Newman N, Brennen J, Howard P (2020) Navigating the 'Infodemic': how people in six countries access and rate news and information about Coronavirus. https://g8fip1kplyr33r3krz5b97d1-wpengine.netdna-ssl.com/wp-content/uploads/2020/04/Navigating-the-Coronavirus-infodemic.pdf
Phillips G, Creaton A, Airdhill-Enosa P, Toito'ona P, Kafoa B, O'Reilly G, Cameron P (2020) Emergency care status, priorities and standards for the Pacific region: a multiphase survey and consensus process across 17 different Pacific Island Countries and Territories. The Lancet Reg Health-Western Pac 1:100002
Ramachandran S, Palazzolo J, West MG, Evans M (2020) Coronavirus cases strain New York City hospitals. The Wall Street J. https://www.wsj.com/articles/coronavirus-cases-strain-new-york-city-hospitals-were-getting-pounded-11584719908
Rangachari P, Woods L, J. (2020) Preserving organizational resilience, patient safety, and staff retention during COVID-19 requires a holistic consideration of the psychological safety of healthcare workers. Int J Environ Res Public Health 17(12):4267
Rees EM, Nightingale ES, Jafari Y, Waterlow NR, Clifford S, Pearson CA, Jombart T, Procter SR, Knight GM, CMMID Working Group (2020) COVID-19 length of hospital stay: a systematic review and data synthesis
Rodriguez-Morales AJ, Cardona-Ospina JA, Gutiérrez-Ocampo E, Villamizar-Peña R, Holguin-Rivera Y, Escalera-Antezana JP, Alvarado-Arnez LE, Bonilla-Aldana DK,

Franco-Paredes C, Henao-Martinez AF, Paniz-Mondolfi A (2020) Clinical, laboratory and imaging features of COVID-19: a systematic review and meta-analysis. Travel Med Infect Dis 101623
Sharma K, Ferrara E, Liu Y (2020) Identifying coordinated accounts in disinformation campaigns. arXiv preprint arXiv:2008.11308
Steel ZL, Safford HD, Viers JH (2015) The fire frequency-severity relationship and the legacy of fire suppression in California forests. Ecosphere 6(1):1–23
U.S. Central Intelligence Agency (2019a) The World Factbook: Northern Mariana Islands. https://teacherlink.ed.usu.edu/tlresources/reference/factbook/geos/cq.html
U.S. Central Intelligence Agency (2019b) The World Factbook: Guam. https://teacherlink.ed.usu.edu/tlresources/reference/factbook/geos/gq.html
US Census Bureau (2010). Decennial Census Datasets. Accessed January 20, 2021 from: https://www.census.gov/programs-surveys/decennial-census/data/datasets.2010.html
U.S. Department of Health and Human Services (2019a) Diabetes and Native Hawaiians/Pacific Islanders. https://www.minorityhealth.hhs.gov/omh/browse.aspx?lvl=4&lvlid=78
U.S. Department of Health and Human Services (2019b) Heart Disease and Native Hawaiians/Pacific Islanders. https://www.minorityhealth.hhs.gov/omh/browse.aspx?lvl=4&lvlid=79
Vériter SL, Bjola C, Koops JA (2020) Tackling COVID-19 disinformation: internal and external challenges for the European Union. The Hague J Diplomacy 15(4):569–582
Vogus TJ, Sutcliffe KM (2007) Organizational resilience: towards a theory and research agenda. In: 2007 IEEE international conference on systems, man and cybernetics. IEEE, pp 3418–3422
Wildavsky A (1991) Searching for safety. Transaction Publishers, New Brunswick, NJ
Winfield N, Barry C (2020) Italy's health system at limit in virus-struck Lombardy. The Associated Press. https://apnews.com/article/837274f1bab9af1aab12f1b9481b2d62

Chapter 5
Complexity, Interconnectedness and Resilience: Why a Paradigm Shift in Economics is Needed to Deal with Covid 19 and Future Shocks

William Hynes, Benjamin D. Trump, Alan Kirman, Clara Latini, and Igor Linkov

Abstract The Covid 19 pandemic illustrated the interconnectedness of a range of human-made systems and the need to pay more attention to the resilience of these systems in the face of shocks and disruptions. Since the socio-economic system is changing and self-organising itself in a way which is difficult, if not impossible, to reconcile with existing economic theory. In an increasingly complex and interdependent system, the aggregate phenomena that emerge do so as a reflection of the interaction between all the participants. The system is constantly evolving and is neither in, nor converging towards, a steady state. Thus, a new paradigm is needed to build and manage more resilient systems. This is one which places analysis in a wider systems and networks perspective. This requires both innovation of economic tools, methodology and policy, and the repositioning of the field of economics in relation to other critical fields such as the environment, engineering, science and politics at the analytical and rhetorical levels and through the integration of policies in practice.

Keywords Resilient economic systems · Economic theory · COVID-19 · The economy

W. Hynes · A. Kirman · C. Latini
New Approaches to Economic Challenges (NAEC) Unit, Office of the Secretary General, OECD, Paris, Ile-de-France, France

B. D. Trump · I. Linkov (✉)
Engineer Research and Development Center (ERDC), US Army Corps of Engineers, Concord, MA, USA
e-mail: Igor.Linkov@usace.army.mil

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_5

5.1 Introduction

The Covid-19 pandemic has disrupted various elements of economies and global finance, from complex international supply chains to consumer spending on recreation, hospitality, and retail (Hynes et al. 2020a). Human-made systems can be fragile and vulnerable to endogenous stresses, as well as to exogenous shocks. Such disruption may arise from within these systems, as in 2008 with the financial system, or externally, as with the systemic shocks stemming from the Covid-19 pandemic. In some complex adaptive systems, there are tipping points that signal radical and sudden changes in behaviors, leading to instability or crisis, that may be amplified due to negative feedback loops between institutions and markets—and within and across borders that extend beyond national regulatory perimeters.

To deal with future systemic shocks, more innovation is needed in the development of tools, methodologies, and policy instruments within the field of economics. This will also involve the repositioning of the field of economics in relation to other critical fields, such as environmental, social, and political affairs. This repositioning must not only manifest at the analytical and rhetorical level but also through the difficult integration of policies in practice.

We are faced with a socio-economic system that is growing increasingly complex and interdependent. In such a system, the aggregate phenomena that emerge do so as a reflection of the interaction between all the participants in the system. The system is constantly evolving and is neither in, nor converging towards, a steady state. Thus, forecasting cannot be solely based on extrapolations from the past nor on the analysis of the behavior of an isolated, "representative" individual or firm.

Perhaps the most important lesson from Covid-19 and the Global Financial crisis is that our socio-economic systems are evolving fast and becoming more and more distant from our old basic economic model. Making efforts to reform the economy so that it resembles the model more closely through increasing flexibility and deregulation may not be helpful. We need to develop better analysis of the system as it is and not as we might like it to be. This is essential in understanding how to increase the robustness of the resilience performance of a system. In particular, if optimizing complex systems makes them unstable, then policymakers need to rethink fundamental objectives such as increasing productivity, innovation, and economic growth. As researchers studying complex physical systems have found, attempts to optimize or harden a complex system can instead render it more brittle and vulnerable to systemic disruption and collapse (Didier et al. 2012).

This chapter examines why a new paradigm in economics is needed to deal with shocks like Covid-19. It examines the complex nature of the Covid phenomenon and outlines how a systems resilience approach can help address it.

5.2 Why a New Economic Paradigm is Needed

The orthodoxy in economics is not as clear-cut as in the natural sciences, and thus multiple perspectives are simultaneously present and pursued. Consequently, the underlying economic narrative has frequently changed. In the last century, there have been two dominant schools of thought. The 1929 stock market crash and the Great Depression gave rise to the Keynesian school of economics as the ruling paradigm. Keynesian economics set full employment as its major goal and established the welfare state. This also gave rise to a wider spectrum of government intervention in the market and in the creation of the welfare state. However, during the 1970s, the economy experienced stagflation, which is the simultaneous occurrence of economic stagnation and high inflation. Keynesian economics was both unable to provide solutions for this problem and unable to provide responses for the oil crisis and other shocks.

The Chicago School proposed the alternative and new paradigm of neoclassical economics. Under the auspices of the free-market economic theory led by the Chicago School, much focus has been on the idea of market efficiency and how this can be achieved. One approach that has been widely implemented is the deregulation of business and the reduction of taxation. This, so the argument goes, reduces frictions to competition, and the more "perfect" competition there is, the better. However, this approach has neglected to fully consider the environmental or social externalities of such policies. As evidenced in the period from the 1970s until today, inequality has not improved, and in many cases, has become more extreme. Furthermore, the effects of human-created emissions on the planet are having severely negative consequences. In effect, the linkages between systems were not thought about deeply in the pursuit of productivity growth.

During the period of significant economic growth in many Western countries prior to 2008, policies liberalizing capital flows and deregulating derivatives encouraged financial market interconnectedness. Contemporary economic thinking held that the economy operates efficiently and nearly at full capacity with occasional exogenous disturbances that are quickly addressed before coming back to equilibrium. Approaches such as dynamic stochastic general equilibrium (DSGE) models metaphorically frame the international economy as a machine with predictable and relatively constant modes of behavior and interactivity between people and organizations (Hynes et al. 2020a).

The large-scale disruption of the economic system during the 2008 crisis and the Covid crisis tests this philosophy, revealing oversimplified representations of economic systems and human behavior within the leading economic models of many major institutions and governments. Richard Bookstaber's "*Four Horsemen of the Econopalypse*" summarizes these models' formation and assumption flaws: computational irreducibility, emergence, nonergodicity, and radical uncertainty (Bookstaber 2017). These concepts refer to omissions in model representations and failures to foresee influential innovations or mischaracterizations of the system-scale implications of individual actions. They also indicate that some realities must be lived to be known, especially in complex systems.

Computationally irreducible systems have outcomes that cannot be summarised by equations of motion. Instead, they must be experienced or—in the case of models—simulated period-by-period in order to find out what actually happens. Doyne Farmer from Oxford describes the "world economy where heterogeneous, global production networks (50 million firms with billions of physical links) interact with household networks (2 billion households, 3.3 billion workers and trillions of links to consumed products), a web of contracts (trillions), and ownership patterns where a few firms and individuals own almost everything". It is not possible to reduce this complexity to a system of equations (Hynes et al. 2019).

Emergent phenomena are situations in which the system's actions differ from the actions of the individuals in it. In other words, the individuals' actions contribute to outcomes at the system level that deviate from the agents' actions, and in some cases, countermand the agents' actions or even bring harm to them, as with stampedes. Economic and financial systems are not always self-stabilising when they get knocked off course by exogenous shocks. Instead, the macroeconomy is inherently intricate and interlinked and offers complex interactions on individual levels that give rise to emergent properties at the macro level and endogenous shocks. Non-ergodic systems' outcomes depend critically on history and context, so that every situation is different and can produce outcomes that differ significantly from previous situations that are similar but not the same (Fullenkamp 2019). In other words, the future doesn't always look like the past.

Finally, radical uncertainty (also known as Knightian uncertainty) means that not only are the probabilities of various events and disturbances unknown, but the event space itself is not fully known (Fullenkamp 2019). In 2018, the former European Central Bank President Trichet (2010) recalled that during the economic and financial meltdown, the traditional tools at his disposal were of little use to address the serious economic policy challenges facing his institution (Hynes et al. 2020a).

There are differing perspectives on how to respond to these fundamental problems. Some argue that economics needs significant reform, but it should be done essentially through extending and modifying existing frameworks. Specifically, the idea of the economy as an equilibrium system should be preserved, but more behavioral and institutional realism should be introduced, including more allowance for various market failures made. Political economy concerns should be revived, and more empirical data utilized (Beinhocker and Hanauer 2014).

On the other hand, many experts today believe a more radical reframing of the field is needed. Specifically, the equilibrium framework should be abandoned in favour of complex systems, dynamic, reflexive, and evolutionary approaches, high degrees of behavioral and institutional realism, and the adoption of newer analytic methods such as computer simulation, network theory, and big data statistical approaches.

Many macro-economists continue to rely upon DSGE models as their basic tool for economic modelling tasks. These models make a number of assumptions about individuals and the economy that are at odds with how other fields of research have evolved. Fields as diverse as statistical physics, ecology, and social psychology now generally accept that systems of interacting individuals, be they people, particles, or molecules, will not produce the sort of behavior that corresponds to the behavior of one average unit of the system in isolation (Hynes et al. 2020a).

While these disciplines now study the emergence of non-linear dynamics as a result of the complex interactions between relevant actors, many leading economic models are steeped in traditional theoretical maxims that contend that rational individuals optimize their activity and behave in an identical manner in isolation as well as in crowds. The behavior of a whole socioeconomic system cannot be deduced from the behavior of its components. This economic paradigm is not validated by empirical evidence, and does not have sound theoretical foundations. As Andersen (1972), a Nobel Laureate in physics, explained, "more is different." New laws emerge as the number of interacting units increases. The dependence on an approach which ignores these problems, could, if used as a basis for policy decisions, lead the global economy toward its next crisis.

The engineering resilience of systems (referenced in short as "system resilience) remains key in fighting the current socio-economic consequences of Covid-19. However, macroeconomics has tended to neglect system properties such as tipping points, non-linearity, asymmetry, and interconnectedness. When it comes to building resilient systems, these are not minor parts of the system; rather, they define it. Macroeconomics must embrace cross-sectoral, multidisciplinary collaboration in the process of policy formulation by taking proper account of the crucial linkages between issues generally treated separately within different specializations and scientific and institutional "silos" (Hynes et al. 2020b).

Systems thinking fully considers such interconnections by treating these individual systems as intra- and inter-connected. Such an approach, which could be implemented through the development of agent-based modelling, network analysis, and machine learning, has the potential to generate a more holistic picture of these varied cross-effects. A concrete example would be the ability of agent-based models to endogenously reproduce the characteristics of the business cycle without external effects such as supply or demand shocks. The current state of global affairs presents the opportunity for another paradigm change in economic thinking: a paradigm change centred on the idea of the economy as a complex adaptive system. Such a new approach requires not only a theoretical framework but also an expanded set of tools that can reflect the paths and outcomes of the current world, and allow for research and policy into how to improve it (Ramos et al. 2019).

5.3 A Complex Systems View of the Covid 19 Pandemic

In a linear, Newtonian world, actions cause predictable reactions. Today's complex system of environmental, socio-political, and economic systems, however, is constantly being reconfigured by human behavior and is simultaneously continuously affecting that behavior. In such a world, a small change can be transmitted and amplified by the interconnectedness of the system to have enormous consequences, far beyond the time, place, and scale of the initial perturbation. In 2007–2008, problems in a national home loan market escalated into a financial crisis that almost destroyed the global banking system. The consequences of the 2008 crisis were still being felt ten years later because it provoked an economic recession that in turn caused political and social upheaval (Hynes et al. 2020b).

The Covid-19 crisis is another illustration of how systems change each other. The initial cause, as in previous coronavirus outbreaks, was a transmission from animals to humans of a virus. When we look in more detail at how this happened, we will probably find that a range of social, economic, and environmental changes contributed to creating conditions where zoonosis could become so damaging—for example, changing land-use patterns and agricultural practices. However, we shouldn't stop at the immediate interactions. We could argue that the 2020 health crisis was made far worse by the 2008 financial crisis, or more precisely, the austerity measures that left many health systems without the basic resources such as protective clothing needed to cope with a sudden, unexpected upsurge in the number of patients. Covid-19 also shows how subjective factors such as trust in institutions and willingness to follow their advice and instructions, or the sentiment of belonging to a community, can influence how a disaster unfolds. A full understanding of such factors requires an approach based on integrative economics, which calls on the insights and methods of a range of disciplines needed to paint a realistic picture of how the economic system is shaped and helps shape the larger "system of systems" of which it is part. Furthermore, systems thinking allows us to identify the key drivers, interactions, and dynamics of the economic, social, and environmental nexus that policy seeks to shape, and to select points of intervention in a selective, adaptive way. Critically, this allows us to emphasize the importance of system resilience to a variety of shocks and stresses, allowing systems to recover from lost functionality and adapt to new realities regarding international economics, societal needs, and human behavior, as well as the risks of a more unpredictable climate (Hynes et al. 2020b).

A recent paper published by the U.K. Royal Society (Johnson et al. 2020) shows that emerging infectious diseases in humans are frequently caused by pathogens originating from animal hosts, and that virus transmission risk is highest from animal species that have increased in abundance and even expanded their range by adapting to human-dominated landscapes. Impacts on ecosystems due to changes to socio-economic systems, such as the introduction of intensive agriculture, thus play a role in creating or aggravating epidemic risk (Hynes et al. 2020b). One study looking at the emergence of infectious diseases calculated that since 1940 intensive agriculture has been associated with more than 25% of all infectious diseases that emerged in humans and more than half of all infectious diseases that spilled over from animals to humans (Rohr et al. 2019).

Ferguson et al. (2020) provided simulations of Covid-19's diffusion, which indicated that the United Kingdom's health service would be overwhelmed and might face 500,000 deaths if the government took no action. This led to the implementation of restrictions on social movement. Using a similar modeling approach, simulations for the United States suggested 2.2 million deaths if no actions were taken. After this prediction was shared with the White House, new guidance on social distancing was issued.

Epidemiologist Joshua Epstein outlined the global spread of pandemics with a focus on Covid-19, in which the interaction between the infection dynamics (created by the pandemic) and the social dynamics (created by fear) produce volatile outcomes. This includes the idea of a coupled contagion: the pandemic and fear about it (which affects health and economic behavior), and how the interaction thereof produces volatile dynamics. Individuals contract fear through contact with the disease-infected (the sick), the fear-infected (the scared), and those infected with both fear and disease (the sick and scared). Scared individuals—whether sick or not—withdraw from circulation with a certain probability, which affects the course of the disease epidemic proper (Hynes et al. 2020b). If individuals recover from fear and return to circulation, the disease dynamics become rich and include multiple infection waves, such as occurred in the 1918 influenza pandemic (Epstein 2014).

One could push the argument further, using the example of the financial system. The two epidemics, contagion and fear, operate in tandem, and the behavior of individuals is changed. The movements in capital markets engendered by the change in decisions of market participants, who were initially affected neither by the virus nor by fear of it, may set off an epidemic of market movements. This can lead, as we have observed recently, to a crash of unprecedented proportions.

5.4 Systems Thinking and Resilience Approaches

In order to promote positive social and economic change, a range of policies has to be integrated, including educational, demographic, employment, well-being, and technology and innovation policies. Systems thinking provides a methodology to achieve a better understanding of the behavior of complex systems and to improve the assessment of the consequences of policy interventions. Growing complexity and interdependence have made various systems (e.g., economic, public health, cyber, etc.) susceptible to widespread, irreversible, and cascading failure (Hynes et al. 2020b).

The policy response to emergency situations should be two-fold: address immediate concerns, and propose an approach to dealing with the longer-term issues the pandemic highlights. In the short term, that means identifying the people and activities most affected, assessing how measures to help them will impact others, and underlining that difficult trade-offs between health, economic, social, and other goals are inevitable. In the longer term, an approach that reacts to the systemic origins and impacts of major shocks is needed if policies are to be effective. The Covid-19 crisis also shows how important it is to keep resources in reserve for times when unexpected upheavals in the system prevent it from functioning normally (Hynes et al. 2020b). Furthermore, given the interdependence of our economies and social systems, the pandemic also highlights the need for strengthened international cooperation based on evidence to tackle systemic threats and avert systemic collapse.

System resilience is a term of rising popularity during the Covid-19 pandemic. Governments worldwide have the opportunity to adopt a systemic, anticipatory approach to reinforcing resilience as a response to the interconnected challenges facing modern societies. These challenges, such as natural hazards, aging populations, global migration, and digitalization, are compounded by their potential to disrupt cyber, information, societal, and infrastructural systems with lasting consequences.

Traditional approaches of risk assessment and management focus primarily upon hardening systems so that they are able to absorb threats before breaking. However, these approaches are inappropriate, prohibitively expensive, or both for many of the issues governments have to deal with. While risk-based strategies seek to decrease a system's exposure to specific shocks through "hardening," resilience approaches presume that shocks will occur over time and emphasize the process of recovery with the prospect of necessary adaptations being made (Jüttner and Maklan 2011; Trump et al. 2018; Linkov et al. 2018a, b). Furthermore, risk-based approaches can neither predict the proximate causes and timelines of the next financial crisis, nor sufficiently harden global financial markets and economic supply chains from the inevitable crisis contagion (Hynes et al. 2020a).

Though resilience-based approaches cannot predict the cause of the next global recession, they can limit the scope of contagion and dramatically improve the pace and scale of economic recovery relative to the 2008 crisis. Ben Bernanke has agreed with this analysis, arguing against the standard "rational expectations" approach which is at the heart of many standard models when he said, "I just think it is not realistic to think that human beings can fully anticipate all possible interactions and complex developments. The best approach for dealing with this uncertainty is to make sure that the system is fundamentally resilient and that we have as many fail-safes and back-up arrangements as possible" (Bernanke 2010).

A systems approach can promote cross-sectoral, multidisciplinary collaboration in the process of policy formulation: it takes proper account of the crucial linkages between issues generally treated separately within different specialisations and scientific and institutional "silos." In order to promote positive social and economic change, multiple policies have to be integrated, including educational, demographic, employment, well-being, and technology and innovation policies. Systems thinking provides a methodology to achieve a better understanding of the behavior of complex systems and to improve the assessment of the consequences of policy interventions.

Serious disease outbreaks such as Covid-19 are the result of systemic properties, and in this case, emergence in particular. Emergence describes a process whereby a situation arises through the interaction of a number of actors and influences, without any intention to create that situation. Helbing (2013) and others have noted that the consequences of failing to appreciate and manage the characteristics of complex global systems and problems can be immense.

Striving for maximum efficiency and optimisation, such systems have neglected resilience against disruptions (Marchese et al. 2012; Linkov et al. 2020), although shocks stemming from disruptions may leave governments, the public, and the environment in a weakened state. More specifically, the concentration of industrial capacities and economic activity into smaller and more efficient sectors, up to the international level, has produced highly lucrative yet fragile supply chains and economic exchanges. The disruption of these systems could have sweeping effects in unexpected areas. While this has provided considerable opportunities, it has also made the systems we rely on in our daily lives (e.g., international supply chains) vulnerable to sudden and unexpected disruption, as the result of either an external shock, the way the system has self-organized or a combination of both (Jüttner and Maklan 2011; OECD and FAO 2019). The 2011 earthquake and tsunami in Japan, for example, exposed the limits of just-in-time supply chain organisation, and highlighted the importance of flexibility, diversification, and adaptability (Fujimoto 2011; Golan et al. 2020).

Such risks have been thoroughly described by leading economists and scholars since the onset of the 2007–2009 financial crisis, yet primarily in an abstract context, although Andrew Haldane, the Bank of England's Chief Economist, did argue in 2009 that "the spread of epidemics and the disintegration of the financial system—each is essentially a different branch of the same network family tree" (Haldane 2009). A key question, therefore, is focused not upon whether systemic risk would cause substantial cascading losses to the international economy, but rather on what type of disruption would trigger such a chain of events in the first place (Hynes et al. 2020b).

Engineering resilience and disaster resilience have been a focus of specific parts of public administration, for instance, military and public health authorities. Resilience must become a core philosophy and mode of analysis within system management and operation to ensure these systems are able to continue to function despite disruptions like Covid-19. Rather than rely solely upon the ability of system operators to prevent, avoid, withstand, and absorb any and all threats, resilience emphasises the importance of recovery and the potential for adaptation in the aftermath of disruption (Linkov et al. 2021).

A resilience mindset acknowledges that the infinite universe of future threats cannot be adequately predicted and measured, nor can the effects thereof be fully understood. Resilience acknowledges that massive disruptions can and will happen, and it is essential that core systems have the capacity for recovery and/or adaptation. Consideration must be given not just to hardening the healthcare system but a range of critical systems connected to it. This involves examining how risk is absorbed and mitigated by these systems and how they will adapt, if necessary (Linkov et al. 2018a, b; Ganin et al. 2016, 2017).

The Covid-19 outbreak has led to a crisis with considerable cascading losses for public health but also for much of the global economy, with concordant high social costs. National governments are struggling to absorb the shock generated by the pandemic, but in time the international community will overcome the crisis and begin the recovery phase. The crisis shows how important it is to keep resources in reserve for times when unexpected upheavals in the system prevent it from functioning normally (and the argument can be made for not depleting natural resources). Given the interdependence of our economies and social systems, the pandemic highlights the need for strengthened, evidence-based international cooperation (building on existing frameworks for emergency preparedness) with specific policy recommendations to enhance systemic resilience.

Based on the resilience literature, specific recommendations for building resilience to contain epidemics and other systemic threats include:

(1) Ensure that systems, including infrastructure, supply chains, economic, financial, and public health systems, are designed to be resilient, i.e., recoverable and adaptable.
(2) Develop methods for quantifying resilience so that trade-offs between a system's efficiency and resilience can be made explicit and can guide investments.
(3) Control system complexity to minimize cascading failures resulting from unexpected disruption by decoupling unnecessary connections across infrastructure and making necessary connections controllable and visible.
(4) Manage system topology by designing appropriate connections and communications across interconnected infrastructure.
(5) Add resources and redundancies in system-crucial components to ensure functionality
(6) Develop real-time decision support tools integrating data and automating selection of management alternatives based on explicit policy trade-offs in real-time (Hynes et al. 2020a, b).

5.5 Conclusions

In 2015, Bill Gates said, “We are not prepared for the next outbreak” (Gates 2015), and suggested creating an army of specialists from many disciplines to meet whatever crisis or epidemic might arise. 27 million people viewed the talk in which he made this comment, but as he noted in 2020, nobody in power heard the message. We are now in the midst of a systemic upheaval. In the spirit of Gates’ call, international policymaking should look to better anticipate, prepare for, and build resilience for future crises.

The radical uncertainty associated with complex systems makes it impossible to predict where the next crisis will come from; nevertheless, this should not stop us from learning from the past to prepare a systemic response for the future. One lesson from Covid-19 is that crises do not repeat themselves. The fact that we were able to contain previous coronavirus crises such as SARS led to a sense of complacency in some instances about our ability to prevent any future crisis. We cannot afford to be complacent about the other grave crisis we are facing: the climate emergency. In systemic terms, this is not a shock, with all that implies of a sudden, unexpected occurrence, but more of a stress. Systems analysis teaches us that stresses are non-linear. The system may continue to function more or less normally for an extended period and only degrade slowly, but it can then reach a tipping point from which it cannot recover, and collapse can then be extremely rapid.

Resilience-based approaches strengthen a system's ability to absorb, recover from, and adapt to a wide array of upheavals. This can include aiding individuals, communities, and larger groups to cope with adversity and even adapt in positive ways to take advantage of the opportunities that disruptions may offer. The emerging field of resilience analysis provides a theoretical foundation that can be applied within available tools of governance and policymaking to better prepare the complex economic and financial systems for systemic disruption and help to avoid collapse. Striving for system resiliency will provide more responsive and effective protections of economic prosperity than the historically problematic methods and tools currently available to most governments (Hynes et al. 2020a).

A resilience-focused philosophy and strategy can help soften the blows of future crises by reducing the aggregate period of losses, translating into considerable unrealized income, increased unemployment, and the exacerbation of countless social ills. Though it is not possible to fully anticipate, prepare for, and harden global and national human-made systems against the wide universe of possible threats that may arise in the years to come, it is far more time- and cost-effective to engineer and govern the various facets of the global economy in a manner that is recovery-driven, not merely loss-averse or profit-seeking. The 2020 Covid-19 Recession is a clear indication that global disruption may arise at any time and from a variety of catalysts and have sweeping and unpredictable consequences. Yet, with a resilience-centred focus, it may be possible to avoid such a slow global recovery as that of the 2008 Global Financial Crisis, and to help sustain and even increase international economic activities and capabilities in the years to come.

Economic analysis is often the most important tool for policy-making. However, given that the socio-economic system is changing and self-organizing itself in a way which is difficult, if not impossible, to reconcile with existing theory, economics has to change too. Policy cannot be based on extrapolations from the past or analysis of the behavior of an isolated individual. System-analysis models have to improve too, to better integrate real-world dynamics such as social and behavioral heterogeneity (Hynes et al. 2020b). This will help to represent social dynamics and complex collective decision-making and facilitate the evaluation of the effectiveness of policies and their systemic impacts.

A promising approach is to integrate existing modeling tools from different fields, for example linking environmental models with economic growth and trade models. This extends the boundaries of what is modeled and allows for broader ranges of interactions to be assessed in policy interventions. Going beyond the integration of existing tools may involve pioneering applications and innovative methodologies and tools in several areas, including explicit accounting for uncertainty, multiple agents with strategic interactions, bounded rationality, including consumption preferences and consumer choices, and network effects linked to complex interconnectedness and systemic risks.

A fundamental challenge in dealing with systemic risk, and one which economic models and approaches are not designed to deal with, is understanding the system as a complex network of individual and institutional actors with different and often conflicting interests, values, and worldviews. Superimposed on this network are the potential risk events with ill-defined chains or networks of interrelated consequences and impacts. A resilience mindset acknowledges that the infinite variety of future threats cannot be adequately predicted and measured, nor can their effects be fully understood. Adopting such an approach means rethinking our priorities, and especially the roles of optimization and efficiency. The science of systems engineering teaches us that when you try to optimize one part of a complex system, you can end up destabilizing the system as a whole.

Disclaimer: The views and opinions expressed in this article are those of the individual authors and not those of the U.S. Army or other sponsor organizations.

This chapter is based, in part, on prior published research in the special issue on “Risk and resilience in the time of the COVID-19 crisis” (Igor Linkov and Benjamin D. Trump, editors) of Springer’s Journal *Environment Systems and Decisions, v40(2), 2020*.

References

Anderson PW (1972) More is different. Science 177(4047):393–396. https://links.jstor.org/sici?sici=0036-8075%2819720804%293%3A177%3A4047%3C393%3AMID%3E2.0.CO%3B2-N
Beinhocker E, Hanauer N (2014) Capitalism redefined. Democracy 2014(31):30–44
Bernanke B (2010) Interview with the International Herald Tribune (IHT), May 17th 2010
Bookstaber R (2017) The End of Theory: financial crises, the failure of economics, and the sweep of human interaction. Princeton University Press, Princeton, NJ
Didier T, Hevia C, Schmukler S (2012) How resilient and countercyclical were emerging economies during the global financial crisis? J Int Money Financ, Elsevier 31(8):2052–2077. https://doi.org/10.1016/j.jimonfin.2012.05.007
Epstein J (2014) Agent_Zero: toward neurocognitive foundations for generative social science. Princeton University Press, Trenton
Ferguson NM et al (2020) Impact of non-pharmaceutical interventions (NPIs) to reduce COVID19 mortality and healthcare demand. https://doi.org/10.25561/77482
Fujimoto T (2011) Supply chain competitiveness and robustness: a lesson from the 2011 Tohoku earthquake and supply chain “virtual dualization”. Manufacturing Management Research Center Discussion Paper N°362. https://merc.e.utokyo.ac.jp/mmrc/dp/pdf/MMRC362_2011.pdf
Fullenkamp C (2019) The End of Theory: financial crises, the failure of economics, and the sweep of human interaction. Œconomia 9(1):189–192. https://doi.org/10.4000/oeconomia.5367
Ganin AA, Kitsak M, Marchese D, Keisler JM, Seager T, Linkov I (2017) Resilience and efficiency in transportation networks. Sci Adv 3(12):e1701079. https://doi.org/10.1126/sciadv.1701079
Ganin AA, Massaro E, Gutfraind A, Steen N, Keisler JM, Kott A, …, Linkov I (2016) Operational resilience: concepts, design and analysis. Sci Rep 6(1):1–12. https://doi.org/10.1038/srep19540
Gates B (2015) The next outbreak? We are not ready. https://www.ted.com/talks/bill_gates_the_next_outbreak_we_re_not_ready/discussion. Accessed 2 Step 2020

Golan MS, Jernegan LH, Linkov I (2020) Trends and applications of resilience analytics in supply chain modeling: systematic literature review in the context of the COVID-19 pandemic. Environ Syst Decis 40:222–243. https://doi.org/10.1007/s10669-020-09777-w

Haldane AG (2009) Rethinking the financial network. BIS Rev. 53. https://www.bis.org/review/r090505e.pdf

Helbing D (2013) Globally networked risks and how to respond. Nature 497(7447):51–59. https://doi.org/10.1038/nature12047

Hynes W, Trump BD, Love P, Kirman A, Galaitsi SE, Ramos G, Linkov I (2020) Resilient financial systems can soften the next global financial crisis. Challenge. https://doi.org/10.1080/05775132.2020.1822660

Hynes W, Trump B, Love P, Linkov I (2020) Bouncing forward: a resilience approach to dealing with COVID-19 and future systemic shocks. Environ Syst Decis 40:174–184. https://doi.org/10.1007/s10669-020-09776-x

Hynes W, Naumann K, Kirman A (2019) New analytical tools and techniques to better understand systems. 17–18 September 2019, OECD Conference Centre. https://www.oecd.org/naec/averting-systemic-collapse/SG-NAEC(2019)6_New_analytical_tools_and_techniques.pdf

Johnson CK, Hitchens PL, Pandit PS, Rushmore J, Evans TS, Young CC, Doyle MM (2020) Global shifts in mammalian population trends reveal key predictors of virus spillover risk. Proc R Soc B 287(1924):20192736. https://doi.org/10.1098/rspb.2019.2736

Jüttner U, Maklan S (2011) Supply chain resilience in the global financial crisis: an empirical study. Supply Chain Manag Int J 16(4):246–259. https://doi.org/10.1108/13598541111139062

Linkov I, Trump BD, Poinsatte-Jones K, Love P, Hynes W, Ramos G (2018) Resilience at OECD: current state and future directions. IEEE Eng Manage Rev 46(4):128–135. https://doi.org/10.1109/EMR.2018.2878006

Linkov I, Trump BD, Keisler J (2018) Risk and resilience must be independently managed. Nature 555(7694):30–30. https://doi.org/10.1038/d41586-018-02567-0

Linkov I, Carluccio S, Pritchard O, Ní Bhreasail Á, Galaitsi S, Sarkis J, Keisler JM (2020) The case for value chain resilience. Manage Res Rev 43(12). https://doi.org/10.1108/MRR-08-2019-0353

Linkov I,Trump BD, Golan M, Keisler JM (2021) Enhancing resilience in post-COVID societies: by design or by intervention? Environ Sci Technol Article ASAP. https://doi.org/10.1021/acs.est.1c00444

Marchese K, Paramasivan S, Held M (2012) Bouncing back: supply chain risk management lessons from post-tsunami Japan. Industry Week, 1–3. https://www.industryweek.com/theeconomy/article/21949237/bouncing-back-supply-chainrisk-management-lessons-from-posttsunami-japan

OECD/FAO (2019) Background notes on sustainable, productive and resilient agro-food systems: value chains, human capital, and the 2030 Agenda. OECD Publishing, Paris. https://doi.org/10.1787/dca82200-en

Ramos G, Hynes W, Müller J-M, Lees M (2019) Systemic thinking for policy making—the potential of systems analysis for addressing global policy challenges in the 21st Centuary. OECD Conference Centre. https://www.oecd.org/naec/averting-systemic-collapse/SG-NAEC(2019)4_IIASA-OECD_Systems_Thinking_Report.pdf

Rohr JR, Barrett CB, Civitello DJ, Craft ME, Delius B, DeLeo GA, … , Remais JV (2019) Emerging human infectious diseases and the links to global food production. Nat Sustain 2(6):445–456.https://doi.org/10.1038/s41893-019-0293-3

Trichet J-C (2010) Reflections on the nature of monetary policy non-standard measures and finance theory. Speech by President of the ECB, Opening address at the ECB Central Banking Conference Frankfurt. https://www.ecb.europa.eu/press/key/date/2010/html/sp101118.en.html. Accessed 2 Step 2020

Trump BD, Florin M, Linkov I (2018) IRGC resource guide on resilience, vol 2. Lausanne (Switzerland): International Risk Governance Center (IRGC)

Chapter 6
Enhancing Current Practice from the Natural and Manmade Hazards Domain to Pandemic: Insights from the Italian Case

Scira Menoni

Abstract The chapter highlights the several similarities between emergency planning and preparedness needs for natural and manmade hazards and those associated with a pandemic. The added value of developing integrated plans following an "all hazards" approach is discussed. A grid of indicators to evaluate the quality of emergency plans is proposed revisiting a similar one that was developed during a collaboration with the Regional Government of Lombardia for assessing municipal civil protection plans. The grid is then applied to the pandemic preparedness and planning tools as available in Italy to respond the current Covid 19 crisis.

Keywords Emergency planning · Pandemic preparedness · Hazard response · Italian response to COVID-19

6.1 Introduction

The initial response to the pandemic has been dealt with almost exclusively as a medical problem; after some weeks of lockdown implemented more or less strictly in different countries, and now in what is labelled as recovery, or initial stages of it, other expertise is also consulted (mainly economists as for the repercussion on economy and jobs due to the containment/mitigation measures) but this is done in separated settings, with limited interaction with those taking the measures aimed at mitigating, tracing and attempting to control the spread. In both cases, an opportunity was missed to consider the management of the pandemic in a systemic fashion, seeing the many integrating, interlacing, interconnected issues that a government should take care of in the management of such a complex crisis. Few

S. Menoni (✉)
Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Milan, Italy
e-mail: scira.menoni@polimi.it

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_6

have framed the problem as a disaster management issue, recognizing the many parallelisms that exist between this crisis and many others experienced in different countries in the last few decades, albeit due to other hazards (mainly natural and technological threats) and at a much smaller scale. Furthermore, some recent events had more global effects that should have at least ring an alarm bell regarding what could easily escalate into a global crisis, like the Fukushima earthquake-tsunami and nuclear accident in 2011 (see Nanto et al. 2011) and the Eyjafjallajökull eruption in 2010 (see Oxford Economics 2010).

In this chapter we aim at discussing the many similarities existing between the two and the advantages that the treatment of the pandemic could get from lessons learnt regarding pitfalls in the management of other types of hazards yet leading to very similar deadlocks and failures. Generally, disaster scientists consider the whole cycle from prevention to impact, emergency management, recovery, reconstruction; here the focus is limited to emergency and early recovery preparedness or lack of, in order to show through practical examples not only the many parallelisms but also the possibility to cross fertilize knowledge and practical solutions among different fields of disaster management.

In addition, our aim is to suggest that whilst integrated risk and crisis management could greatly benefit from such sharing and cross fertilization of knowledge and experience, it could also serve to maximize and optimize the use of necessary resources for preparedness, both material and immaterial. First, the meaning of "integrated" should be explained. In emergency and recovery planning, there is a tendency to be hazard specific, so one will prepare a plan for seismic emergencies, floods, volcanic eruptions, chemical contamination incidents, etc. This approach is justified by the differences the hazard scenarios present and that often have an impact on the assessment of what is more exposed and vulnerable. Whilst the phenomenon/incident scenarios must be certainly tuned to the specifics of each distinct phenomenon, it is also often the case that the potential remedies—and the type of logistics and organizational procedures that must be put in place—overlap and are very similar from one case to the other. This means that some protective devices that work in case of a toxic contamination may work as well for a biological threat, and that the logistics of evacuation or extra bed in a hospital due to mass casualties may not be very different if an earthquake, a tsunami or a hurricane have occurred. Recognizing such commonalities in terms of number of potentially exposed people and assets, of their vulnerabilities, for example, in terms of accessibility to hospitals and rescue services, may save time in the development of plans and permit sharing resources that can be easily adapted from one emergency to another.

When speaking of immaterial resources, time is certainly a key one, especially for workers in emergency or medical services. Being able to commit to planning and emergency preparedness is time consuming before requiring some costs to be borne: a great advantage can be appreciated if some phases, some parts of plans and preparation can be considered common to a number of disaster occurrences. This though calls for a much more integrated type of preparation and response than is usually the case and put all the burdens on the development of adequate scenarios, on the scientific modeling of what may be the impact, not limited to direct physical damage but also to induced and systemic type of consequences, on the development of more sophisticated planning processes that require thinking, studying and research. The latter are generally poorly developed or even non-existent as for too long emergency and contingency planning has been considered as a practitioners', first responders' issue that does not need any theoretical and academic research. Based on our previous long lasting experience in developing emergency plans together with different administrations for a variety of jurisdictions and types of threatening events, we argue for more in depth and rigorous thinking and development of purposeful models and training based on scientific evidence of likely scenarios (Menoni 2013).

6.2 Methodological Aspects

Even though we have started working on crisis management related issues since the start of the pandemic, it is clear that the time that has passed does not allow for in depth investigation of all issues even limiting to emergency planning and preparedness. This chapter provides preliminary findings and contribution to discussion that will need further research and observations in the months and years to come. In order to provide some clarity on how the findings here below are provided, this section is devoted to explicit what factors have been considered, and what sources of information consulted and elaborated, considering two distinct aspects: (i) on the one hand emergency planning for natural and man-made hazards; and, (ii) on the other hand, evaluation of preparedness in the pandemic case, showing the relevant similarities in the assessment of limitations and gaps in the overall approach to planning and preparedness. Both will provide examples from the Italian case.

As for emergency planning for natural and technological threats, our observations are based on almost twenty years experience with public administrations at different levels in developing emergency plans for jurisdictions from municipal, to provincial and regional levels for a variety of threats. We have developed plans for hydrogeologic, fire and technological hazards, external emergency plans according to the European Seveso Directive, plans for drought. The more recent experience has been carried out in the last 14 months supporting the preparation of comprehensive risk assessments in the case of a dam failure. Based on this experience and on the long term collaboration with the Civil Protection Department of some regions (including the Umbria and the Lombardia Regions), an evaluation grid to assess the quality of emergency plans is proposed.

Such grid has been used to assess the quality of emergency preparedness in the case of pandemic in Italy and in Lombardia, following a literature brief review of evaluation efforts that were carried out in the recent past. Relevant documents prepared by national and Lombardia Region authorities for the case of pandemic have been consulted, jointly with articles on the effectiveness of such plans in the case of Covid 19 that have been published since the Sars-Cov 2 outbreak. In order to address consistently issues and fallacies found in documents, observed in the everyday development of the pandemic in Italy, an extensive analysis of reports in newspapers, radio, and articles provided by different platforms on Covid 19 have been consulted. To corroborate the reasoning and the resulting deficiencies/ strengths of the response in terms of emergency management in relation to existing emergency plans some interviews were conducted with personnel working in four distinct hospitals in Italy.

The first interviewed is a physician working in the ICU of a private hospital in the outskirt of Milan; the second is the Head of the Equipment and Machinery Department of three hospitals in the same district in Central Italy the largest of which was converted into a Covid 19 health care center; the third is the Head of the ICU of the Lodi Hospital in Lombardia that faced the most critical and intense surge of patients being in the initial hotspot of the pandemic in Italy (Paglia et al. 2020). The last interviewed is a young trainee working at the Infectious Diseases Ward of the San Matteo Hospital in Pavia. The interviews were semi-structured, as respondents provided different perspectives and replies given their role in the institution, their direct experience with treating or dealing with patients of Covid 19, their prior knowledge and familiarity with the problems.

6.3 Emergency Planning and Preparedness: Issues and Pitfalls in Current Practice

Recent papers on pandemic preparedness made comparisons or highlighted the similarities with preparedness to other hazards and threats. For example, a report by the Edmund Safra Center for Ethics at Harvard (Rosenthal and Jones 2020) compared the military and the public health domains in the U.S., and concluded that while preparedness against war is considered substantially a public good—and as such provided with adequate resources and surge capacity in case of need—the latter has been underfunded for a long time. Preparing extra capacity of basic means such as PPE, staffing, and even coordination protocols with private hospitals has not been considered as a priority, despite the many reports that were produced by the CDC and other administrations and of the many fallacies table top and other simulation exercises highlighted.

A very interesting comparative assessment of national plans of EU member States was prepared for influenza type of disease dates 2006 (Mounier-Jack and Coker 2006). The study utilized a ranking method to evaluate the completeness and the quality of national plans on the basis of a system of indicators derived from the WHO Guidelines for the preparation of a pandemic preparedness plan. According to the results, the average score for completeness was 54% (within a rather wide interval between the least complete 24% and the best ones 80%) and rather similar for quality, 58% on average within an interval from 27 to 86%. Despite the relatively good level of plans, important pitfalls could be recognized in most of them, for example in the absence of a clear identification of the target groups and stakeholders of the plans, in the insufficient consideration of maintenance of essential services, putting plans into practice, and public-health interventions. Furthermore, "health-care supplies such as protective equipment, antibiotics, reagents, and medical equipment were mentioned in 90% of plans. However, none gave estimates of the magnitude of need. In many cases, decisions about what to purchase and stockpile were designated to local authorities" (Mounier-Jack and Coker 2006, p. 1409).

Regarding the drawback associated with burdening local authorities with tasks that they will clearly have difficulties to perform, Burkle (2010) commenting on the study by Cocker and Mounier-Jack (2006, p. 24) in Asian Pacific countries similar to the one carried for Europe, pointed out that "important gaps, weaknesses, and inconsistencies remained, with the need for operational level planning and to adequately address operational responsibility at the local level." In the conclusions to their study the two Authors were basically highlighting the need for a cross-scale coordination that is global for tasks such as information sharing and mutual provision of stock in the most critically affected areas whilst developing at the same time local operational capacity.

Elsewhere, we have noted that pandemic preparedness, planning and crisis management would benefit from a stronger interaction between planning systems and tools that are used for natural and manmade hazards at least from a logistics and risk management perspective and approach (Menoni and Schwarze 2020). Such opinion is shared by other scholars (Wing-Keung Chan 2020). This was certainly the view of the Federal Ministry of the Interior in Germany that under the Law on civil protection and federal disaster aid developed a National Risk Assessment envisaging two main scenarios, one based on a large flood event, the other on a pandemic, named "Modi Sars." The reading of the proposed scenario is certainly extremely instructive as it provides striking similarities with the current Covid 19 pandemic. The high level of detail of the proposed scenario and the envisaged counteracting measures makes it more similar to a plan than to a mere assessment exercise and reveals a rather advanced level of anticipation of potential problems in many fields of concern, including consequences at the economic and social levels. The existence of such planning capacity provides an important element of explanation on the good performance of Germany especially in the course of the first phase of the crisis (from March to September). Interestingly enough, for the sake of comparison, the National Risk Assessment provided by the Italian Department of Civil Protection and dating December 2018 focused on the many natural hazards to which the country is exposed, but pandemic is not mentioned at all.

In Italy, emergency planning has been considered and correctly so a key element of preparedness against natural and technological disasters since a couple of decades at least and significant effort has been invested, including economic incentives, by national and regional governments into local planning. According to the assessment updated last February 2020,[1] 88% of Italian municipalities have their

[1]See the website of the Italian Civil Protection Department: https://www.protezionecivile.gov.it/servizio-nazionale/attivita/prevenzione/piano-protezione-civile/mappa-piani-comunali.

emergency plans, 78% in the Lombardia Region. The datum can be considered a good achievement. However, an important point that has been raised by examining the content of the document that have been developed regards the quality of such plans, their actual capacity to support action and intervention in case of an extreme event. In 2016 we had the opportunity to collaborate with the Civil Protection Department of the Lombardia Region in developing a grid to assess the quality of emergency plan that considered several aspects, from the accomplishment of all formal deliberations that are required to enforce the plan, last update, to more technical aspects related to the consideration of appropriate scenarios, identification of resources and key responsibilities. In Table 6.1 the grid has been revisited to be of more general validity than restricted to the Italian case and including additional aspects such as questions related to the consideration of systemic vulnerabilities in scenarios that were not included in the evaluation carried out by the Lombardia Civil Protection administration. In the following the main aspects in the first column of the grid are discussed.

6.3.1 Development of Plans According to Scenario Planning and Its Limits

Scenarios are considered a plot describing the development of a potential hazard in its real manifestation on the ground (Strong et al. 2020). It may range from purely qualitative (thus taking a narrative form illustrated with some figures and maps) to more quantitative ones, thus deriving from a model that is based on the most relevant indicators to depict quantitative aspects of both the phenomena and the exposed people and assets. In between a wide range of possibilities are given in the form of semi-quantitative scenarios that describe quantitatively those indicators for which models and data are available without neglecting qualitative information that can be crucial in providing an understanding of what may be the most relevant obstacles in the field and the complexities due to the interaction of systems and systems' component in a more comprehensive fashion. At the very least, a scenario should provide the extent of the area that may be affected, the number of victims involved, the duration of both the phenomena and the crisis, the impact on different sectors, especially those that are fundamental to manage the emergency itself (such as hospitals, lifelines, rescue services) (Menoni et al. 2017b). Developing good scenarios is perhaps one of the most difficult tasks ever (Ringland 1998); in exercises that we have developed as part of emergency training we were able to verify practically that anticipating the future is somehow psychologically more difficult than describing the past (even though in both cases the information and data available are lacking and fragmented, see Rescher 2009). It is in the technological hazards domain that the practice of developing scenarios as a base of preventative actions and of contingency planning is more advanced and structured, with specified methods and steps to be followed and providing a clear connection

Table 6.1 Grid providing relevant indicators to assess the quality of emergency plans (Author's own elaboration)

Main aspects	Indicators	Criteria for assessment
Plans developed on the basis of comprehensive damage scenarios	Worst case phenomena/ incidents are considered	Yes/no motivation for not considering worst cases
	More frequent and likely cases are fully considered	Yes/no
	Scenarios are prepared for each hazard in the area	Yes/no and enumerate the hazards in the area
	Potential enchained and cascading phenomena included	Yes/no and enumerate most likely cascading events
	Exposed population is evaluated	Yes/no provide assessment procedure
	Exposed assets and critical targets are considered	Yes/no provide assessment procedure
	Highly vulnerable social groups are considered	Yes/no provide assessment procedure
	Highly vulnerable assets and critical infrastructures are assessed	Yes/no provide assessment procedure
	Fast reconnaissance mechanisms are in place	Yes/no provide details including reference to EU services
	Longer term damage and usability assessment procedures and tools are in place	Yes/no refer to past experiences and advancement in damage and loss assessment
	Intervention to reduce progression of damage and securing assets and people is defined	Yes/no enumerate type of actions possible for different hazards
Systemic vulnerabilities and second order effects	Accessibility to potentially affected areas is assessed considering also enchained events	Yes/no explicit what models are used
	Accessibility to staging and evacuation areas is assessed	Yes/no explicit what models are used
	Potential inter-sectoral impacts are considered (i.e. critical infrastructures)	Yes/no what type of interdependency are considered including those specific to the context

(continued)

Table 6.1 (continued)

Main aspects	Indicators	Criteria for assessment
Plans implying logistics aspects considering multiscale implications	Staging areas for emergency resources are defined	Yes/no assess if adequate with respect to potential scenario
	Evacuation and sheltering areas are defined also legally	Yes/no link to the urban master plan
	Lifelines and basic required services are in place in emergency/ sheltering areas	Yes/no assess eventual problems in facilities provision
	Potential consequences in wider areas than those directly affected are considered	Yes/no list the regions/ provinces/municipalities
Plans consider appropriate timelines and duration of effort	Early warning systems are in place technically but also operationally	Monitoring systems exist and are effective; social aspects of early warning have been considered
	The sequence of early activation including appropriate means is determined	Between first interveners, critical facilities
	Different phases of the emergency and associated activities detailed	Each hazard (and certainly the combination of) requires a distinct phasing and type of activities
	Long duration is appropriately acted upon (shifts, resources)	Some emergencies may last longer than few days/weeks, but months
Plans are operational and operationally known and practiced by involved actors (including the public)	Plans are regularly updated	Yes/no and last update (general or partial)
	Plans are delivered to all actors	Yes/no according to checklist
	Training and Exercises take place	Yes/no what type of training and exercises
	Communication of the plan to involved stakeholders including the population	How the plan is communicated to stakeholders not in civil protection and to the population
	Plans published in the internet	Yes/no
	Is a 24 h service in place?	Yes/no
	Plans identify key people responsible for different functions and resources	Names and details

between the unfolding of an accident inside a hazardous installation with the potential development of the latter outside the plants' fences thus involving people and assets in the community where the plant is located (Khan et al. 2015).

In more recent years such methods and steps have been considered also for developing scenarios due to natural hazards (Simmons et al. 2017), yet the capacity to transform a physical phenomenon into not only direct physical damage to people and exposed objects and assets but also indirect damage due to systemic interconnections is still limited and unevenly developed in different hazard domains (more in the seismic risk for example). Given the complexities of developing scenarios, there are some relevant fallacies in the process that are discussed in literature. Here the most relevant in our experience will be highlighted. First there is a limit in the details that scenarios are able to incorporate. One may suggest that scenarios should be general enough to cover a number of possibilities, however lacking the adherence to a specific context and place, where some details may be crucial in determining the evolution of an event can turn into a critical shortcoming. For example, a phenomenon or an accident may reach the area where a hospital or an emergency control center is located: this can be envisaged only with a more detailed and targeted scenario. There is no doubt though that the resulting information is strategic for emergency management. Inevitably not all the details can effectively be introduced, the "art" of making scenarios, though, should address exactly those elements that may be crucial for the response and may hamper it entirely (Scholz and Tietje 2002).

A second limit derives from the generally insufficient description and analysis of the territorial context where an emergency may unfold: the accessibility to crucial services, the features of the latter that make them less or more vulnerable to a certain threat, the areas where people are more concentrated, are all information that should guide the allocation of resources and prioritization on the ground. A third well known limit regards the decision on what scenarios are actually followed upon. Inevitably not all scenarios can be considered, apart from the above mentioned intrinsic limitations on how far our imagination can go, there is also the need to restrict infinite possibilities to a manageable number of scenarios. So often plans are based on the more frequent ones (that will be those more plausibly faced) whilst the so called "worst cases" are often dismissed based on their low probability or on the lack of evidences or information related to what may actually happen. In this regard, lessons learnt from across countries and sectors could enhance significantly the knowledge base from such information and understanding can be built in a similar vein as it occurs in the aviation industry. It must be noted though that is rarely the case, best practices and lessons learnt are followed up only in a limited, laudable number of cases (the Nedies project, see Colombo and Vetere Arellano 2002; the Late Lessons from Early Warning series, see Gee et al. 2013). It needs also to be pointed out that often "worst case" are grounded on previous experience and embed little imagination regarding how dynamic and evolving conditions in the natural and built environment may actually lead to more dramatic outcomes than those experienced in the past. An example can be brought from the bushfires in Australia. In 2009 the sequence of events that led to the Black Friday was already considered as “worse” than any worst case scenarios envisaged before. Nevertheless the extensive fires that ravaged Australia for weeks in 2019 were considered unprecedented and setting a new threshold for what can be considered as “worst case”. Yet in our own work with public administrations developing a variety of plans for natural and man made hazards, including accidents in chemical installations, authorities are often reluctant to consider scenarios they may be clearly unprepared to face. However, a whole line of literature on crisis management suggests that envisaging extreme scenarios is augmenting the capacity to succeed in a real event, because it creates the conditions to think and reflect about potential responses, thus improving the overall preparedness and triggering the search for adequate resources and skills (Boin and Lagadec 2000; Alexander 2000).

6.3.2 Appropriate Consideration of Systemic Impacts and Vulnerabilities

Gaps and shortcomings in the development of comprehensive scenarios are also due to the general lack of systemic understanding of emergencies and particularly of complex crises. The need for a systemic perspective in complex crisis has been highlighted by many scholars in disaster management and resilience studies (Park et al. 2013). It stems from the understanding that an impact on crucial nodes and components of systems has the potential to reverberate spatially and functionally farther away and across many other sectors that depend on the system that has been directly affected. In many occurrences the systemic failure is due to the physical impairment of a crucial component, network or an entire system many other depend on. However, in some cases, systemic damage may occur even without significant physical damage occurring in one or multiple components of systems. This was the case for the blackout in Italy in 2003 or even more evident the halt to flights after the Eyjafjallajokull volcanic eruption. In both cases the consequences of the incident and of the precautionary stop to flights triggered multiple failures and impacts in different sectors of economy and life.

Most plans are based on scenarios that are a mix of hazard analysis and rough definition of exposed assets and people, with limited, sometimes poor or even inexistent consideration of vulnerabilities. The latter are not only physical ones, related to the potential for physical impairment, but often systemic vulnerabilities that develop across systems and components. Systemic vulnerabilities reflect the interconnection among supply chains, critical infrastructures, and the role environmental and even morphological conditions play on the coping capacity, on the accessibility to crucial areas or resources. Issuing an order of evacuation for a large city to protect from an impeding hurricane or volcanic eruption entails significant economic costs and is disruptive of social life, services, economy. Rarely emergency plans consider such potential costs, evaluate the cost benefit of issuing such orders or provide graduated alternatives tailoring the latter to the expected severity of the event.

Even though the relevance of second and higher order damage that may exceed by far direct physical damage has been highlighted in literature (Menoni et al. 2017a) and even though systemic vulnerability in complex urban systems has been researched since long time, such a systemic perspective has been missing or only marginally considered in most emergency plans. Many assumptions on the possibility to dispatch in short time needed material and resources to affected areas often underestimate the damage to access ways, definition of staging and evacuation areas often is done without adequate consideration of legal access to such areas and to the difficulties that may be encountered in equipping them with basic services in case a large number of people need to be relocated there. It is virtually impossible to consider all potentially relevant systemic interdependencies and interrelationship in an emergency plan; however, some important ones could be targeted. A comprehensive scenario approach, coupled with a serious analysis of past cases and experiences could help in this regard.

6.3.3 Appropriate Consideration of Spatial and Temporal Scales

A third gap relates to multi-scale considerations both in time and space. As for the former, emergency plans are usually considered as a close document including steps and procedures to be accomplished by a pre-definite set of administrations and involving the affected population. Rarely the plan is graduated with respect to a potential timeline of a disaster. If the latter is brief, this sort of "one shot" plan can be considered exhaustive as return to normal can be conceived in a relatively short time. However, if the duration of the event is prolonged over weeks or even months, problems arise in the sustainability of certain measures and in the provision of material and resources that need to be prepared for. As for spatial scale issues, not only there is often poor or insufficient connection between national or federal, regional and local plans that sometime overlap and some others leave ample margins of indetermination regarding who should be doing what, but there is also scarce understanding of what factors and vulnerabilities can be actually managed at what scale. For example, issues related to critical infrastructures and accessibility cannot be solved locally only, unless a crucial node of a network is located in one specific area. When the emergency is likely to involve several places at the same time scattered over a regional or national territory, there is the need to coordinate the response and the provision of resources at higher levels than the local one. Still in many countries, the decision to apply for larger scale provisions reflects only a subsidiarity principle, with poor comprehension of the interlinkages and the risk aspects that actually link one level to another.

6.3.4 Operationality

The three points discussed above partially determine another important failure consisting of the difficulties encountered in current bureaucracies and administrative arrangements to allocate time and thought to potential crisis and non-routine work, that result in lack of operational knowledge and skills necessary to enact many provisions of the emergency plan. This happens at all levels: at the national failures in identifying the places where some materials and resources will be mostly needed, at the regional scale in preparing teams and personnel that will be dedicated to certain tasks during an emergency and will be able to guide the actions at the local level. Finally, at the local level such lack of operational capacity translates into poor exercising and inability to wear correctly certain protective means, in maneuvering emergency vehicles, in inadequate maintenance of stocks and emergency devices (generators exist but fuel is not available).

6.4 Italy: Gaps in Preparedness and Planning that Emerged in the Covid 19 Crisis

In this section we will try showing how the limits and drawbacks of emergency planning that are common in the field of natural hazards actually proved to be equally relevant in the case of the pandemic. The main idea is to propose the cross-learning and cross-fertilization of practices and improved solutions between the field of disaster studies and pandemic, showing that in many regards deficiencies were not mainly (or not only) medical, but mostly organizational and therefore entailing a type of expertise that is not limited to medicine and even not to public health, intended as the field providing health care capacity and means as well as guidance for maintaining people healthy and preventing diseases in a given community. The perspective of a disaster researcher is particularly relevant as most actions and activities of public health bodies as well as hospital and care facilities relate to ordinary times, with limited efforts and resources devoted to imagining and preparing for mass casualties, epidemics and pandemics. This is at least the condition in many Western countries. The situation is clearly different in developing and poor countries where epidemics are frequent and war create the conditions for frequent episodes with mass casualties and mass entrances in hospitals and ambulatories. It is also interesting to note that being prepared for certain types of incidents, for example terrorist attacks or earthquakes, has not necessarily guaranteed equally good performance in the case of the Covid 19 crisis, as scenarios to be considered are specific even though significant overlapping in resources and means can be foreseen.

The evaluation grid proposed in Table 6.1 has been applied to the pandemic planning and preparedness as can be assessed based on the current response in Italy as shown in Table 6.2. The most relevant indicators are then discussed in the following sections.

Table 6.2 Application of the evaluation grid to the pandemic preparedness and planning in Italy (Author's table)

Main aspects	Indicators	Criteria for assessment
Plans developed on the basis of comprehensive damage scenarios	Degree of severity considered for scenarios development	Only scenarios similar to the influenza like type of disease were considered
	Scenarios are prepared for each hazard in the area	National, regional plans are generally sectoral and do not consider cascading, co-occurring phenomena
	Exposed population is evaluated	No estimation of potential peak number of sick people have been assessed
	Highly vulnerable social groups are considered	Some consideration about elderly (but not with commorbidities) has been found in plans
	Fast reconnaissance mechanisms are in place	Some consideration to surveillance mechanisms of pandemic is mentioned in plans but not detailed within the organizational public health framework
Systemic vulnerabilities and second order effects	Identification of separated routes inside hospitals	Was generally not envisaged in hospitals emergency plans and not highlighted in higher level (regional/national) guidelines/plans
	Potential inter-sectoral impacts are considered (i.e. critical infrastructures)	Whilst closure of clusters of infection is mentioned in the national plan (2006) economic and social impacts of the latter are not addressed

(continued)

Table 6.2 (continued)

Main aspects	Indicators	Criteria for assessment
Plans implying logistics aspects considering multiscale implications	Identification of areas and buildings external to hospitals for large number of patients or to separate suspected cases	The potential need for areas and facilities to be converted into hospitals to treat the surge demand of infected patients was envisaged but few details were provided
	Internal reorganization of wards	The provision of additional beds in case of mass casualty was generally envisaged in hospitals emergency plans but not ways to create separation between infected and non infected as well as filtering zones between the two
	Identification of buildings to be used for quarantine	Yes/no list the regions/ provinces/municipalities
Plans consider appropriate timelines and duration of effort	Early warning systems are in place technically but also operationally	Surveillance is addressed in all plans, but no detailed mechanisms and procedures for early warning are provided considering the national ad regional health care organizational framework
	The sequence of early activation including appropriate means is determined	It is not
	Different phases of the emergency and associated activities detailed	The national plan (2006) identifies the different phases and provides indications for each that often require coordination of lower levels of government, that often though are not available publicly and apparently not known by key stakeholders
	Long duration is appropriately acted upon (shifts, resources)	Long duration is not envisaged in plans. Plans are also not addressing the need to shift personnel if the duration is of some months

(continued)

Table 6.2 (continued)

Main aspects	Indicators	Criteria for assessment
Plans are operational and operationally known and practiced by involved actors (including the public)	Plans are regularly updated	Plans have been prepared following an epidemic occurrence not as a preventative measure
	Plans are delivered to all actors	Regional plans were known to high level managers and head of ICUs but not shared with doctors, nurses and hospital personnel
	Training and Exercises take place	No training was taking place so that personnel had to get fast instruction on the procedures for clothing and unclothing in the filtering zones
	Communication of the plan to involved stakeholders including the population	Plans could be found in the internet but no specific page for pandemic risk could be found in "peace time"
	Is a 24 h service in place?	Yes
	Plans identify key people responsible for different functions and resources	Plans were identified general level responsibilities and a chain for the provision of PPE. This in fact has worked with some criticalities

6.4.1 Existence of a Pandemic Plan

The very first step to speak about the quality and the usefulness of any plan is ascertaining if such plan actually does exist or not. And subsequently as an obvious following issue if the plan was known to the relevant stakeholders, how often was it updated, if and how often was it tested in drills and exercise. Those questions are all relevant if we make a comparison for example in the case of Italy. In fact as for natural hazards and chemical risks, a very significant effort has been devoted by the national department of Civil Protection but also by regional authorities to make sure that emergency plans exist at the provincial and municipal level and they are known to key actors such as mayors, technical staff in the municipalities including local police forces, firemen. In the case of pandemic, evidences in the analyzed reports and information sources, further confirmed by the interviewed, suggest that some plans did exist albeit not necessarily covering pandemic due to multiple causes and pathogens, often restricted to the type of pathogen that had just been experienced when the planning effort was undertaken. In Europe at least, most efforts followed the Sars epidemic in 2003, the H5N1 "birds" pandemic threat in 2005–2007, the

H1N1 swine flue pandemic in 2009 and the Ebola in 2014–2016. National plans were prepared in Europe by all countries also pressured by the leading role of the European Commission.

Some regional plans were also prepared in 2006 and even audited. In Italy, a very blatant case brought by the media regards an audit that has been debated by the Regional Government of Lombardia in 2010 regarding the fallacies that were detected during the H1N1 incident and that should have been acted upon but were not. Among the more noticeable points two important fallacies that were highlighted in the audit still persisted in the current Covid 19 pandemic. First the lack of a monitoring network that should have been guaranteed by local public health bureaus in charge of programming and monitoring resources for health care, that are present and disseminated in the territory and that are closer to communities with respect to hospitals. They should have guaranteed a certain level of alert in case of increased number of patients with the same type of influenza-like type of diseases but this has not actually occurred, rather a reform decided by the Regional Government culminated in 2017 in the creation of a limited number of Health Agencies and further centralization of most relevant activities on the hospitals' system and leaving without a clear reference the community doctors, those who can first ring an alarm in case of unusual type of disease and/or number of patients. Having a net on the ground that is able to detect anomalies in given areas and before patients go to the hospital is a crucial element in order to detect cases early enough and also prepare hospitals for a possibly higher number of patients presenting similar unusual symptoms. The reform that aimed at making the whole system more efficient economically and managerially made it also less resilient, in the sense of reducing redundancies and giving less room to decentralized agents (such as community and occupational doctors) to raise the attention in case of local clusters of unexpected diseases. The second point that was raised was related to the need to reinforce staff capacity in elderly care facilities in order to reduce the need for hospitalization. The audit highlighted that no action had been taken at the date and it looks like also in the case of Covid 19 such facilities were not specifically targeted as highly vulnerable and potentially capable of reducing the health care capacity of hospitals in case of significant surges in demand.

In all the plans, audits and documents that we have analyzed, though, a big emphasis was on vaccinations, meaning that such plans were not designed with the idea that in case of a new type of pathogen vaccines may not be available and difficult to obtain in a reasonably short time. Such plans manifest that in the absence of a fix able to reduce the infection spread no specific other actions were actually operationally available. As the main focus of such plans was on medical aspects, insufficient consideration was given to the case in which vaccination and/or antiviral are not available for the specific pathogen and more socially disruptive measures must be taken at a much larger scale.

6.4.2 Limitations of Considered Scenarios

This leads to the first of our main points regarding general fallacies observed also in other types of plans more related to natural disasters. In particular, the reluctance or the absence of a scenario based approach. Plans in fact start with the assumption that a certain pathogen (generally influenza like) has the potential of becoming pandemic. The reliance on an assumed type of scenario restricts the possibility to think about unexpected, totally new and surprising cases where the usual type of approach (treatment and vaccination) is not immediately available.

In a scenario of this type, for example, one should have considered to establish very soon a network among laboratories, hospitals and health care facilities to maximize the effectiveness and also the speed of learning from the first treated patients. According to our interviewed this was a crucial point. Such network established on an occasional basis among doctors of different hospitals who knew each other or through early publications, but was not occurring according to a pre-established procedures. In the Lombardia Region plan for reinforcing the health care sector for the initial recovery phase following the Guidelines provided by the Ministry of Health, it is stated that "It might be useful to create a website with restricted access to share recommendations regarding practices and difficulties encountered in their adoption". From the context it can be guessed that the recommendations are also deriving from the continuous updates of knowledge and scientific information that becomes available. The capacity to treat Covid 19 patients has increased dramatically in the first weeks of the pandemic thanks to the informal network and to the increased understanding given unfortunately the first trial and error interventions on the first patients. Therefore the hospitals that received Covid 19 patients at later stages (because they were activated later or because the regions where they are located were reached by the infection later with respect to the initial hotspots) had an advantage in terms of general preparation and also cumulated knowledge on what worked or not.

Furthermore, plans that we have consulted were not granting large room to non-pharmaceutical measures, mentioning in a brief and non-specific way physical distancing, wearing masks, hygiene measures. This is consistent with what has been found in the comparative review of Mounier-Jack and Cocker (2006). Such insufficient consideration of non-pharmaceutical measures meant that systemic aspects of partial or total closures of activities, towns, regions were underestimated or not considered at all. No practical indication of how to pay or compensate for economic consequences of the mitigation measures was provided. This is consistent not only with what has been witnessed in the last months, but also very similar to what occurs in other types of hazards, where worst case scenarios are not considered assuming that the most severe stages of the crisis will not be reached.

A contrasting very relevant example is provided instead by the already quoted Modi-Sars scenario considered in the German National Risk Assessment in 2012. There different aspects were considered including the long duration of three years of subsequent infection waves albeit of diminishing intensity, the initial lack of vaccination and treatment (and the need therefore to use symptomatic treatment mainly), even the relatively long hospitalization period beyond the usual few days required for some patients.

6.4.3 Issues in Multiscale Coordination and Lack of a Systemic Approach

In an ideal world, coordination across spatial scale would have meant to have a logic chain connecting provisions for single hospitals, community health care centres (such as the aforementioned bureaus in Italy) at higher scale coordinating a number of hospitals, community doctors, ambulatories for exams and visits, regional plans and national preparedness plans. The subsidiarity principle that is often recalled for emergency situations would mean that there will be the need to upscale providing more resources and personnel coming from other regions in case the regional forces are not sufficient (including the recalling of retired doctors and nurses). While recalling of doctors and nurses already retired has been done massively, interregional mobility has not been experienced in Italy, even though it could have clearly helped especially in the first days to have specialized ICU personnel instead of having to commit staff with no prior experience through rush training.

The same would be the case of the provision of protective measures. The update of the regional plan that has been analyzed instead did not differ much from the national one, meaning that more duplication of provisions and decisions were likely to occur. In the response to Covid 19 the national and regional governments (also for political reasons) seemed more in competition than collaborating on the issuing of measures and in the provision of resources. The epitome was reached when the regional government of Lombardia decided to build a new hospital very fast using its own consultants in the area of the Milan fair (Portello Fiera). Other regions have made similar decisions, despite of many adverse suggestions by ICU medical doctors who raised the issue related to the lack of staff, highlighting that scarce resources were not only trivially beds or wards, but the specialized personnel needed to treat ICU patients and the specific requirements of ventilators that had to be deployed, for long time and unusual oxygen volumes (in many acute instances even five times more). A rather interesting experience that was reported in the two public hospitals in Lombardia Region related to the fast deployment of means to restructure the internal organization of wards, including intensive units. For example, in the Pavia hospital the oncology unit at the third floor of a building occupied in the first two by the infectious diseases ward was transformed to host additional Covid 19 patients, reaching a peak number of around 90 patients taken care of in the same days. In the first floor, walls were built to divide the unit in two parts, one for patients with relatively mild cases and a sub-intensive care unit for patients requiring oxygen (Asperges et al. 2020).

As far as could be analyzed in existing plans for pandemic but also in the debate regarding the crisis management, such systemic perspective that would have identify critical bottlenecks in the provision of testing capacity, distribution of protective devices and in the meantime recognize the dramatic effects of closure on all sectors of social life and economy was largely insufficient or absent. A more comprehensive plan could have at least addressed the most well known issues related to the transmission of certain type of disease influenza like and coronavirus, even before the release of medical and epidemiological studies, in different workplaces and facilities where crowdedness and closeness occurs on a regular basis and that have been found in the past as potential hotspots of virus spread.

Systemic aspects were underestimated even limiting the consideration to medical type of intervention, especially for those aspects that are more organizational rather than purely medical. Issues in fact can be found regarding the specifics of where large amount of protective devices, needed equipment and materials can be stored and maintained safely overtime, but also regarding the channels through which such devices and means should be provided to those most in need of them (health care personnel, more at risk patients/population groups). Plans have also seldom considered the need to design a proper territorial distribution of such reserve centers and provision channels considering the characteristics of the exposed regions and urban areas, considering indicators such as average age of the population, presence of high risk facilities (such as elderly care), the simple population concentration that can be often considered a proxy of higher rates of infection.

6.4.4 Insufficient Consideration of Time Scale Issues

There was an insufficient appreciation of the long time duration that an event like a pandemic would entail, meaning a significant prolonged stress on the health care system as well as on all societal sectors. Plans we could analyze in Italy were aiming at fast containment and control, were not really preparing for a long term crisis. Whilst we agree with Timmis and Brüssow (2020) that the provision of equipment and protection means is costly and requires the extra-buffer discussed above, yet many aspects of emergency planning and preparedness are organizational and require an approach to decision making that is not the routine one under normal conditions. In Italy for example the declaration of state of emergency on the 31st January and postponed several times since then, provided the possibility to fast acquire resources and allow adjustments to be made in hospitals and in the rapid deployment of camp hospitals. However, the long duration defeats this emergency management approach, especially when the initial recovery is partially overlapping to a prolonged emergency and actually the two phases are much more intertwined than usually considered. This issue is particularly evident in the measures taken to reorganize the health care and mainly the hospitals' system in Italy in June-July in a period of apparently lowering numbers of infections. The mandate that was given by the Ministry of Health mainly consisted in the fast increase of ICU beds and wards capacity for less acute cases of Covid 19 and increase of ambulances for the transportation of patients affected by SARS-COV 2 not only to hospitals but also between hospitals to be redirected to designated as Covid 19 hospitals. Following the Ministerial Gudelines, the Lombardia Region as recalled by two of our interviewed and as written in the Regional Plan, decided to concentrate Covid 19 treatment in 17 hospitals (named Hub) on the basis of certain criteria being: the availability of an emergency unit, an ICU, a ward for infectious diseases. This contrasts though with a reality in which the disease is extremely diffused and one may expect that patients will flow to whatever hospital not necessarily only to those primarily indicated as hubs. Furthermore, the indication is already defeated at the time of writing by the need to fast increase cure capacity lately requested also to non-hub hospitals as hubs are starting getting full. Whilst concentrating the treatment of Covid 19 patients in some hospitals makes sense in terms of efficient allocation of equipment and staff, the second pillar of pandemic response, that is monitoring, surveillance and tracing were treated in a separated document approved on the 5th of August, missing the key aspect of systemic interconnection between hospitalization and early detection for reducing the spread and anticipating the provision of care to less severely affected individuals. The resolution approved on the 5th of August 2020 resembles more a set of recommendations than a plan, practically delegating the operational development of the latter to the 7 Health Agencies whilst overlooking the necessary coordination that should have been guaranteed by the Region.

The Ministerial mandate was to increase the ICU capacity to close the large gap existing with other far better off countries in Europe such as Germany (see Bauer et al. 2020). In fact, the country's access ratio measured by number of beds very 100.000 inhabitants was rather low, with regions that were performing better and regions that were far behind. The problem is that even in regions doing better, like Lombardia, a significant effort still needs to be made to reach the 17/100.000 as required by the Ministry. The comparison between available ICU beds as reported in the Ministry table, the peak occupancy that required fast reallocation and emergency provision of ICU units on the 3rd of April and the proposed target can be seen in Table 6.3. On the one hand the Lombardia Regional Plan foresees to recall the practice adopted during the first surge, that is reallocation of care units

Table 6.3 Comparison between pre-pandemic situation in 2018 in the Lombardia Region with the peak demand in April and foreseen offer according to the Regional Plan (a warning the numbers are not fully comparable as the 2018 number refers only to intensive care unit without considering semi-intensive units that are considered in the second and third column)

ICU accessibility index and number of units at January 2020 in Lombardia Region*	ICU accessibility index and number of units (existing and additionally provided) at the peak of the pandemic on the 3rd of April 2020	ICU accessibility index and number of units required by the national Guidelines and foreseen in the Regional Plan
8,42	13,81	17
842	1381	1798

from other illnesses to Covid 19, and the fast conversion of regular beds to semi-intensive via improvement of equipment and fast works.

Further increase in the absolute number of ICU beds to be provided for the future requires instead extensive construction works and more time to be accomplished, with an estimation of 24 months in the Lombardia Region document. The same document also suggests that the latter time could be significantly reduced by smoother procedures of administrative approval. In a similar vein the plan proposes to move the emergency call center that controls all ambulances dispatched in the Region from the current space allocated within the Niguarda Hospital and that is certainly not adequate to guarantee physical distance between the operators and is in any case too narrow for the needs of a region with 10 Million inhabitants to a renewed buidling. However, also in this case this change will not be immediate. In a nutshell the issue is that permanent long term measures and short term fast redeployment should not be confounded in the same document: fast deployment for an impeding resurgence should have been treated separately from the correct identification of improvement to be implemented in the health care system once the emergency is over.

6.4.5 Lack of Operational Knowledge of Tools

A significant factor diminishing the effectiveness of emergency planning regards the lack of detail necessary to guide operators in the enactment of individual measures mirrored by poor and inexistent operational knowledge by the operators themselves regarding assets and tools that are key components of the emergency plan. This shortcoming is particularly evident at the local level. Writing in a hospital emergency plan that infected patients and those in contact with the latter should be separated from all other patients is clear in theory but requires a careful design of entrances and staging areas already at the acceptance of patients into the hospital. Apparently, in the Lombardia Region, this was actually done at the beginning only in few hospitals, whilst in all the others mixed patients were admitted to triage rooms.

Second, areas hosting infected patients must be separated from the rest of the hospital through a transition zone. However, such prescription does not translate into action unless specifics of rooms, spaces are not foreseen. Similarly, suggesting that in transition areas decontamination should take place implies an operational knowledge by all personnel that will transit there (therefore not only doctors or nurses but also technicians or other workers) of how to unclothe, clothe and decontaminate. Such an operational knowledge requires at least some training. A very interesting experience was reported by the Head of the ICU interviewed: in his hospital a team of Doctors Without Borders operating in Africa and therefore particularly used to deal with infectious diseases were asked to provide fast training in the first days to the hospital personnel. This proved to be particularly effective in order to both teach novels and refresh skills of advanced personnel about basic and very operational aspects of dealing with infectious diseases. In another case the interviewed mentioned that compulsory courses on safety that she had attended at the beginning of her training in the hospital provided little information on the necessary conduct in case of pandemic. Being in an infectious diseases ward personnel was already aware of the need to protect themselves and a filtering room is located at the entrance of each patients' room each equipped with two beds. However specific training on PPEs was provided one month after the beginning of the peak phase of the pandemic in Italy, a situation that was considered a bit paradoxical by the involved personnel, even though it made sense for the staff that was not already dealing on a daily basis with Covid 19 patients.

Similarly, the doctor working in a small private hospital in Milan suggested that the time lag between the first acute period and when they started admitting Covid 19 patients helped them invent fixes in order to guarantee a safe passage through the transition room, for example empting their pockets and disinfect objects before getting outside. Retrospectively it would be of extreme importance to take advantage of the learning that has occurred in the field and include it in more advanced guidelines and good practices for future occasions or other hospitals for example in regions that have been less affected in the first outbreak.

In hospitals there was also lack of training regarding mass casualty procedures that would require not only triage among the differently severe cases, but also the calibration of testing and examination types and capacity targeting and prioritizing differently from what would be done in normal circumstances. Reports of the medical doctors that have been interviewed clearly commented that a sort of stepping back towards older procedures was required in order to guarantee a fast check to deliver immediate care to the maximum possible number of patients. Meaning that faster X-ray had to be preferred to more sophisticated and accurate examinations that nevertheless require much longer time to be executed. This is somehow very similar to what should be foreseen in an emergency plans for natural disasters, as at the beginning only a fast reconnaissance assessment of damage must be carried out to correctly allocate and dispatch rescuers forces. Damage assessment should be carried out by phases responding to different demands arising at different phases of the emergency and first recovery condition. Usability assessments of buildings and later more in depth damage analysis for reconstruction projects can be carried out only once the most acute phase of the emergency has passed. Somehow this is similar to what we were told by medical doctors. First reconnaissance had to be done fast to guarantee at least a preliminary rough check (and a possibility to survive) to the maximum number of people; then when the situation in the wards stabilized more careful and tailored to the subject's need examination was carried out.

6.5 Integrating the Pandemic in More Integrated Emergency Planning and Preparedness Process

There are many good reasons to integrate the risk of pandemic in an overall national, regional and local emergency preparedness and planning process. First because natural disasters and epidemics can be associated in different ways: during mass casualty events it is always feared that mismanagement of the situation may end up in provoking the spread of diseases due to bad hygienic conditions, lack of water, insufficient sanitation facilities, large number of victims. Even more relevantly natural disasters and incidents will occur also during a pandemic a situation that will create extra-burdens for first interveners and the victims themselves (Quigley et al. 2020).

Second because for many aspects the organizational capacity behind provisioning resources and devices for different types of intervention and pandemic is the same or very similar, consisting of identification of appropriate registered providers, procedures and ways to dispatch such provisions, store them adequately, make them available to those needing them in the field. Also from a logistic point of view staging and emergency areas foreseen for some emergencies may be relevant also for camp hospitals (that are actually also foreseen in case of natural disasters), evacuation of hospitals may be required, emptying of hospitals to receive surges of patients may be triggered by different incidents. An on the other hand, the treatment of a natural hazard or a manmade incident during a pandemic has important implications on how rescuers must work and how the latter as well victims behave. In this regard an interesting example is provided by Guidelines of the National Department of Firefighters that have been just released and which detail very precisely not only the usual recommendations in terms of physical distancing, sanitization and PPE but also how an emergency must be dealt with starting from the management of calls in the operational center to dedicated provisions for rescuers' camps. For example, in the former specific questions must be asked to the caller regarding the presence of known infected people and checking if the area is a red zone. As for the latter, beds in tents must be separated by tissues with prescribed height and length. In the absence of such divisions the number of rescuers residing in the same tent diminishes significantly. In the meantime the entire organization of control zones to enter the canteen and other common and storage facilities require larger areas than those usually foreseen for this type of camps. This has in its turn a potential repercussion on emergency plans and the interlinkages with urban master plans in terms of what are the type of areas that are better fit to host in case of need such type of emergency camps and facilities and that in Italy must be already determined and freed from legal impediments according to the current directives for emergency planning. Additionally it is required from teams coming from the same province to stick together without mixing with colleagues from other regions and provinces so as to minimize the potential for closeness between people coming from areas with different level of infectiousness. These Guidelines were the object of a deployment exercise involving 200 firemen that was held in July and proved their effectiveness as none got infected in its aftermath.

A further aspect that deserves larger attention than has been the case until now relates to psychological support for rescuers including health care workers (Alexander and Klein 2009). In fact, mental health disorders suffered by those in charge and involved in emergency operations, especially in mass casualty events and in presence of a large number of victims is a well known risk that should be taken care of during the emergency and especially afterwards. As commented by Cronin et al. (2007), tendency not to turn to psychological support is rather typical of rescuers and has been reported as a worrying conditions that appropriate practices, including involving psychologists in emergency operations so that they become peers of the rescuers and recognized by the latter as legitimate and trustful interlocutors. What was reported by the young trainee in the Pavia hospital instead was a situation in which psychological counselling was attempted in the ward during working hours creating extra-stress to already overwhelmed personnel. Interesting enough the trainee reported that such counselling was better accepted by nurses than by doctors. This condition is in line with similar preliminary findings of a study conducted in the USA regarding the difficulties young medical trainees have encountered in having to deal with the Covid 19 crisis in hospitals' ward, for them the first real practical professional experience (KannampallilI 2020). As a main comment, it can be said that psychological support should be better considered a key component of preparedness; emergency plans should enlarge their focus beyond the practical things to deal with in the emergency field to encompass also social, organizational as well as mental health issues of emergency workers, including firemen, policemen, medical staff (Seynaeve 2001).

6.6 Conclusions

One important lesson that this pandemic has certainly thought the health care system in different Western countries is that resilience runs against pure economic and managerial efficiency, something that is well known to scholars in the field (Longstaff et al. 2010). In order to be resilient a buffer between the perfectly optimal number of beds, devices, resources that you would use in normal times and sudden surges in demand is needed. Resources, personnel and devices need to be provided with some margin, the larger the margin the better the system is able to cope with large increase in demand. The health care system of the Lombardia Region had undergone several reforms as mentioned above, all aimed at making the system more efficient from a managerial perspective and in fact has reached excellent standards of health care provision. However, differences among hospitals are still relevant, between those in the proximal areas to Milan, better equipped and much larger, and small hospitals in smaller cities at the fringes of the metropolitan areas, with limited number of resources where a surge of 10–15 persons needing ICU already overwhelmed the facility's capacity. But it was not only a matter of number of beds and personnel, also installations and equipments at the hospitals are key: in order to provide the quantity of oxygen needed to treat severe hypoxia in the Covid 19 most severe cases, three to four times the normal flux of oxygen was required, hampering the safety of old or simply working at the limit oxygen pipes and machinery. The provision of oxygen has not been a real issue, but required a lot of adjustments, showing even more clearly that developing a functioning emergency plan for hospitals in case of mass casualties or pandemic is in many regards more of an organizational and programming issue based on well-conceived scenarios rather than a purely medical affair.

An additional aspect that was mentioned by the interviewed is the difference between the public and private hospitals. The latter had certainly more resources but what apparently proved to be much more important was the possibility to avoid complex bureaucratic procedures that often created burdens to fast decisions to be quickly implemented. The fact that in private hospitals the owners are closer to the doctors and the head of different departments made a big difference with respect to the situation in which a central regional office is in charge of a large number of health care facilities and the contact between wards' heads with urgent needs and the decision maker who can dispatch resources and personnel is not direct and mediated by a number of bureaucratic steps that may be reasonable under ordinary conditions but cannot be followed during a crisis. This is well known in the field of natural disasters as it has been often reported that delays occurred because of bureaucratic impediments rather than absolute lack of means and yet very few emergency plans contemplate revised and smoother procedures for accessing material and resources in case of sudden urgent requests that frequently arise especially in the first acute crisis.

Second, a truly all hazards approach is currently missing in most emergency plans, certainly in the ones we could observe in the Italian case. The need to consider not only the possibility of co-occurrences but also of enchained and cascading effects is rarely addressed. In the paper different areas of overlapping, potential integration of resources and logistical aspects, organizational improvements suggest that an all hazard approach is necessary, considering also the fact that the same operators will be often in charge of each individual emergency no matter what hazard is involved and that areas and cities that are exposed to multi-hazards are likely to experience different types of events and often also events enchained in the same occurrence.

Third, and coherently with the previous point, a systemic approach is the only one that permits to address the many challenges deriving from interdependent sectors, including indirect damage and losses that may also derive wittingly or not from the mitigation measures themselves and may be more harmful in the medium and longer term than the first order damage they were meant to contrast. Such a systemic approach might benefit from a reform and a new thinking on emergency plans and emergency preparedness. The complexity of large emergencies makes the definition of one plan model that fits all needs obsolete and very ineffective in including the multiple dimensions that are not only technical and logistical, but also human and societal. An important concept that has been gaining acceptance in the last years—and that we had the opportunity to see in practice in the case of the security plan for the Expo exhibition in Milan in 2015—is the development of a constellation of sectoral plans and protocols. The latter are prepared by the agencies and organizations in charge of different activities and tasks and are coordinated by a super-plan that functions like a networked mesh, ensuring that inter-relationships and interlinked requirements are met and effectively dealt with.

Acknowledgements The Author wishes to thank the doctors and technical staff who agreed to be interviewed for this article, namely Dr. Enrico Storti, Head of the ICU at the Lodi Hospital (Lombardia, Italy); Dr. Chiara Tosi, physician a the ICU of the San Donato Hospital in Milan (Lombardia, Italy); Mr. Roberto Gigli in charge of the Machinery and Equipment of the Camerino Hospital (Marche Region, Italy); Ms. Ilaria Gallazzi, physician trainee at the Infectious Diseases Ward of the San Matteo Hospital in Pavia (Lombardy, Italy).

Disclaimer: This chapter is based, in part, on prior published research in the special issue on "Risk and resilience in the time of the COVID-19 crisis" (Igor Linkov and Benjamin D. Trump, editors) of Springer's Journal *Environment Systems and Decisions, v40(2), 2020.*

References

Alexander D (2000) Scenario methodology for teaching principles of emergency management. Disaster Prev Manag 9:2

Alexander D, Klein S (2009) First responders after disasters: a review of stress reactions, at-risk, vulnerability, and resilience factors. Prehosp Disaster Med: The official journal of the National Association of EMS Physicians and the World Association for Emergency and Disaster Medicine in association with the Acute Care Foundation 24(2):87–94

Asperges E, Novati S, Muzzi A, Biscarini S, Sciarra M, Lupi M, Sambo M, Gallazzi I, Peverini M, Lago P, Mojoli F, Perlini S, Bruno R (2020) Rapid response to COVID-19 outbreak in Northern Italy: how to convert a classic infectious disease ward into a COVID-19 response centre. J Hosp Infect 105(3):477–479

Bauer J, Brüggmann D, Klingelhöfer D, Maier W, Schwettmann L, Weiss D, Groneberg D (2020) Access to intensive care in 14 European countries: a spatial analysis of intensive care need and capacity in the light of COVID-19. Nature Public Health Emergency Collection, September 4

Boin A, Lagadec P (2000) Preparing for the future: critical challenges in crisis management. J Conting Crisis Manag 8(4)

Burkle F (2010) Do pandemic preparedness planning systems ignore critical community-and local-level operational challenges? Disaster Med Public Health Prep 4:1

Coker R, Mounier-Jack S (2006) Pandemic influenza preparedness in the Asia-Pacific region. Lancet 368:886–889

Colombo A, Vetere Arellano AL (2002) NEDIES Project: Lessons learnt from flood disasters. Joint Research Centre EUR 20261 EN

Cronin M, Ryan D, Brier D (2007) Support for staff working in disaster situations. A social work perspective. Int Soc Work 50(3):370–382

Gee D, Grandjean P, Foss S, van den Hove S (2013) Late lessons from early warning. Science, precaution and innovation. EEA Report 1/2013, European Environment Agency, Copenhagen

KannampallilI T, Goss C, Evanoff B, Strickland J, McAlister R, Duncan J (2020) Exposure to COVID-19 patients increases physician trainee stress and burnout. PLoS ONE 15(8):e0237301

Khan F, Rathnayaka S, Ahmed S (2015) Methods and models in process safety and risk management: past, present and future. Process Saf Environ Prot 98:116–147

Longstaff P, Armstrong NJ, Perrin K, Parker WM, Hidek M (2010) Building resilient communities: a preliminary framework for assessment. Homel Secur Aff 6. https://www.hsaj.org/articles/81
Menoni S (2013) Emergency planning. In: Bobrowsky P (ed) Encyclopedia of natural hazard. Springer, Dordrecht, pp 273–281
Menoni S, Bondonna C, Garcia Fernandez M, Schwarze R (2017a) Recording disaster losses for improving risk modelling capacities. In: Poljansek K, Martin Ferrer M, De Groeve T, Clark I (eds) Science for disaster risk management 2017. Knowing better and losing less. European Commission, DG-JRC, 2017
Menoni S, Atun F, Molinari D, Minucci G, Berni N (2017b) Defining complete post flood scenarios to support risk mitigation strategies. In: Molinari D, Ballio F, Menoni S (eds) Flood damage survey and assessment: new insights from research and practice. Wiley, AGU (American Geophysical Union) series
Menoni S, Schwarze R (2020) Recovery during a crisis: facing the challenges of risk assessment and resilience management of COVID-19. Environ Syst Decis 40:2
Mounier-Jack S, Coker RJ (2006) How prepared is Europe for pandemic influenza? Analysis of national plans. Lancet 367:1405–1411
Nanto D, Cooper W, Donnelly M (2011) Japan's 2011 earthquake and tsunami: economic effects and implications for the United States. Congressional Research Service. https://digital.library.unt.edu/ark:/67531/metadc99025/m1/1/high_res_d/R41702_2011Mar25.pdf. Last accessed May 2020
Oxford-Economics (2010) The economic impacts of air travel restrictions due to volcanic ash. In: Report for airbus. www.oxfordeconomics.com. Last accessed 20 March 2020
Paglia S, Storti E, Bisagni P, Ferrari P, Manelli A, Delfanti F, Mainardi C, Martinenghi S, Cò F, Di Capua M, Tantardini M, Speranza I (2020) Lodi's experience in handling the first COVID-19 hotbed in Europe. Talian J Emerg Med 9(2):93–101
Park J, Seager TP, Rao PSC, Convertino M, Linkov I (2013) Integrating risk and resilience approaches to catastrophe management in engineering systems. Risk Anal 33:3
Quigley M, Attanayake J, King A, Prideaux F (2020) (2020) A multi-hazards earth science perspective on the COVID-19 pandemic: the potential for concurrent and cascading crises. Environ Syst Decis 40:199–215
Ringland G (1998) Scenario planning, managing for the future. Wiley
Rosenthal M, Jones D (2020) Preparedness and unpreparedness: the military vs. medicine, COVID-19 rapid response impact initiative. White Paper 15
Simmons D, Dauwe R, Gowland R, Gyenes Z, King AG, Riedstra D, Schneiderbauer S (2017) Qualitative and quantitative approaches to risk assessment. In: Poljansek K, Marín Ferrer M, De Groeve T, Clark I (eds) Science for disaster risk management 2017. Knowing better and losing less. European Commission, DG-JRC
Scholz R, Tietje O (2002) Embedded case study methods. Integrating quantitative and qualitative knowledge. Sage Publications, London
Seynaeve GJR (ed) (2001) Psycho-social support in situations of mass emergency. A European Policy Paper concerning different aspects of psychological support and social accompaniment for people involved in major accidents and disasters. Ministry of Public Health, Brussels, Belgium
Strong K, Carpenter O, Ralph D (2020) Scenario best practices: developing scenarios for disaster risk reduction. Cambridge Centre for Risk Studies at the University of Cambridge Judge Business School and Lighthill Risk Network
Timmis K, Brüssow H (2020) The COVID-19 pandemic: some lessons learned about crisis preparedness and management, and the need for international benchmarking to reduce deficits. Environ Microbiol. https://doi.org/10.1111/1462-2920.15029
Wing-Keung Chan D (2020) A reflection on the anti-epidemic response of COVID-19 from the perspective of disaster management. Int J Nurs Sci 7:382–385

Consulted Documents and Legislation

German Bundestag, Printed matter 17/12051, 17th legislative term. Law on civil protection and federal disaster aid. Briefing by the federal government Report on risk analysis in civil protection 2012 (Deutscher Bundestag, 17. Wahlperiode Unterrichtung durch die Bundesregierung Bericht zur Risikoanalyse im Bevölkerungsschutz 2012, Drucksache 17/12051)

Italian Ministry of Health, Piano Nazionale di Preparazione e risposta ad una pandemia influenzale (National preparedness plan to respond an influenza pandemic) (2006)

Italian Ministry of Health, Linee di indirizzo organizzative per il potenziamento della rete ospedaliera per emergenza COVID-19 (art 2 decreto-legge 19 maggio 2020 n. 34) (Guidelines for the reorganization of the hospitals network for the Covid 19 emergency according to article 2 of the national decree 19 May 2020, n. 34)

National Firefighters Organization (Corpo Nazionale dei Vigili del Fuoco) Linee Guida Gestione del rischio operativo connesso all'emergenza Covid 19 (Guidelines for operational risk associated with the Covid 19 emergency), Third Revision, May 12 2020

Regional Government of Lombardia, Piano Pandemico Regionale—Aggiornamento a seguito del manifestarsi della Pandemia Influenzale A/H1N1v (Regional Pandemic Plan—update following the A/H1N1 pandemic), Notice 19/SAN/2009

Regional Government of Lombardia (2010) Valutazione Piano Pandemico Regione attività realizzate durante le fasi 3–4–5–6 della pandemia da virus influenzale A/H1N1, (Evaluation of the plan for pandemics and of the activities carried out by the Region during the phases 3–4–5–6 of the pandemic due to the virus A/H1N1) Official Document n. IX/001046, 22nd December 2010

Regional Government of Lombardia, Approvazione del Piano regionale di Prevenzione 2015–2018 ai sensi dell'intesa Stato-Regioni 13 Novembre 2014. (Approval of the Regional Health Prevention Plan within the agreements between the State and the Regions deliberated on November 13 2014)

Regional Government of Lombardia, Piano di Riordino della Rete Ospedaliera: Attuazione dell'art. 2 del D.L. 34/2020 (Re-organization of the Hospitals Network according to article 2 of the national decree 34/2020 approved by the Region on the 16/06/2020)

Regional Government of Lombardia, Adozione del Piano di potenziamento e riorganizzazione della rete di assistenza, in attuazione dell'art. 1 Law July 17 2020, n.77 (Adoption of the reinforcement and reorganisation of the health care network as for article 1 of the national Law 77 issued on July 17th), Resolution XI/3525, August 5 2020

Rescher N (2009) Ignorance (On the wider miplications of deficient knowledge). University of Pittsburg Press

Chapter 7
Value-Based Optimization of Healthcare Resource Allocation for COVID-19 Hot Spots

Zachary A. Collier, Jeffrey M. Keisler, Benjamin D. Trump, Jeffrey C. Cegan, Sarah Wolberg, and Igor Linkov

Abstract With the emerging COVID-19 crisis, a critical task for public health officials and policy makers is to decide how to prioritize, locate, and allocate scarce resources. To answer these questions, decision makers need to be able to determine the location of the required resources over time based on emerging "hot spot" locations. Hot spots are defined as concentrated areas with sharp increases in COVID-19 cases. Hot spots place stress on existing healthcare resources, resulting in demand for resources potentially exceeding current capacity. This research will describe a value-based resource allocation approach that seeks to coordinate demand, as defined by uncertain epidemiological forecasts, with the value of adding additional resources such as hospital beds. Value is framed as a function of the expected usage of a marginal resource (bed, ventilator, etc.). Subject to certain constraints, allocation decisions are operationalized using a nonlinear programming model, allocating new hospital beds over time and across a number of geographical locations. The results of the research show a need for a value-based approach to assist decision makers at all levels in making the best possible decisions in the current highly uncertain and dynamic COVID environment.

Keywords Value-based optimization · Healthcare resource allocation · COVID-19 hot spots

Z. A. Collier (✉)
Radford University, Radford, VA 24142, USA
e-mail: zcollier@radford.edu

J. M. Keisler
University of Massachusetts Boston, Boston, MA 02125, USA

B. D. Trump · J. C. Cegan · I. Linkov
US Army Engineer Research and Development Center, Concord, MA 01742, USA

S. Wolberg
US Army Corps of Engineers, North Atlantic Division, Brooklyn, NY 11252, USA

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_7

7.1 Introduction

The COVID-19 (SARS-CoV-2) pandemic presents a novel and challenging combination of disease characteristics, including the high risk of inter-human transmission, long incubation times, and presence of asymptomatic carriers, positioning it as a "perfect storm" to impose a strong epidemiological burden on society (Lippi et al. 2020). With the emergence of this pandemic, a central question faced by communities across the globe is how decision makers should prioritize and allocate scarce healthcare resources such as personal protective equipment (PPE) and ventilators (Laventhal et al. 2020; Zaza et al. 2016). Answering the question, "Where will the needs be?" is critical to the successful allocation of resources. From a public health perspective, there is a need to predict the timing and location of areas which will be particularly hard-hit, so that additional resources (e.g., hospital beds, ICU beds, ventilators) can be allocated to lessen the impact of a sudden and rapid influx of admitted patients. Such "hot spots", where a sharp increase in geographically concentrated COVID-19 cases occur, can place a great stress on hospital resources and associated supply chains (Golan et al. 2020).

Hospital beds and ventilators are critical resources for treating patients in any pandemic situation. Excessive demand on existing hospital bed resources results in "capacity strain", which is associated with increased mortality and other adverse health outcomes (Eriksson et al. 2017). The ability to optimize the allocation of scarce healthcare resources in areas which are experiencing, or will likely experience, a surge in demand exceeding capacity, can help to ease the burden on the healthcare system in that area (Meyer et al. 2020).

One resource allocation strategy is to follow a "needs-based" approach, which involves identifying the geographic areas with the largest magnitude of resource needs and allocating resources accordingly. The problem with this approach is that it may result in a suboptimal resource allocation across the national and regional healthcare system, and is essentially reactive in nature. We propose a "value-based" approach, which takes a more proactive and system-wide perspective, based on the long-term value of allocation decisions. Similar perspectives can be seen in the supply chain practice of "demand management" (Croxton et al. 2002), which involves linking and synchronizing demand forecasts with production, procurement, and distribution capabilities to find initiatives which add economic value to the firm's financial performance. Here, instead of measuring economic value added to a firm, we define value in terms of the expected usage of a marginal bed—in other words we seek to obtain, for each new bed added, the greatest use benefit to the greatest number of patients while using the fewest resources possible (Laventhal et al. 2020).

The problem of allocating scarce resources is well-suited to be informed by mathematical optimization models. Mehrotra et al. (2020) developed a stochastic optimization model for the allocation and sharing of ventilators. Billingham et al. (2020) approached the problem of scarce ventilator distribution through a network optimization model. Santini (2020) used integer programming to optimize the allocation of swabs and chemical reagents for COVID-19 testing. However, in time-critical emergency situations, taking an action-oriented perspective is preferred where streamlined, yet informative, "scratch" models are developed to generate insights within a short timeframe (e.g., Kaplan 2020; Manca et al. 2020).

In this spirit, we propose a simple, value-based optimization model for prioritizing hot spots for the allocation of healthcare resources (i.e., new beds) based on an understanding of bed demand and the value of adding additional marginal beds. In this chapter, we describe a simple nonlinear programming model for the decision problem of allocating some number of new hospital beds over time and across a number of geographical locations. The modeling approach is to link the optimization model to epidemiological models which provide uncertain demand forecasts.

7.2 An Optimization Model for Hospital Bed Allocation

The decision problem is to build a limited number of beds across a set of possible locations (modeled at the state level) over multiple time steps (weekly). The number of beds which can be built in a week is limited to a certain maximum capacity. Additionally, it takes some amount of time between when the decision is made to build beds at a location and when they are completed and available for treating new patients. Finally, we assume that the objective of the decision maker in allocating beds is to minimize the total expected shortfall of beds across a given region.

Framed mathematically as an optimization problem, we let the decision variables be denoted by $x(i,t)$, the number of beds to add to state i in week t (therefore there will by i*t decision variables). Let $B_A(i,t)$ be the Beds Available for state i in week t. Allowing for a lag time of n weeks, $B_A(i,t+n) = B_A(i,t) + x(i,t)$ (e.g., if we let n =3 weeks, the $x(i,t)$ beds planned to be built in week 1 will be available for use in week 4). The maximum capacity of beds built per week across a region is defined as $x_{cap}(t)$, which functions as a constraint.

Further, let $B_M(i,t)$, $B_L(i,t)$, $B_U(i,t)$ be forecasted Mean Beds Needed, Lower Uncertainty Bound for Beds Needed, and Upper Uncertainty Bound for Beds Needed, respectively, for state i in week t, as provided by epidemiological forecasts. The Bed Shortfall then is the difference between Beds Needed and Beds Available, i.e.,

$$B_{SM}(i,t) = B_M(i,t) - B_A(i,t) \quad \text{Shortfall Mean Beds} \tag{7.1}$$

$$B_{SL}(i,t) = B_L(i,t) - B_A(i,t) \quad \text{Shortfall Lower Beds} \tag{7.2}$$

$$B_{SU}(i,t) = B_U(i,t) - B_A(i,t) \quad \text{Shortfall Upper Beds} \tag{7.3}$$

Note that a negative shortfall implies that there is a surplus of beds.

Given a mean, lower, and upper estimate for bed shortfalls, the Expected Shortfall is the probability-weighted average of Shortfall Mean Beds, Shortfall Lower Beds, and Shortfall Upper Beds, based on a selected discrete probability distribution. The weights for Mean, Lower, and Upper were assigned arbitrarily as 0.5, 0.25, and 0.25, respectively:

$$B_s(i,t) = (0.5 * \max(0, B_{SM}(i,t))) + (0.25 * \max(0, B_{SL}(i,t))) + (0.25 * \max(0, B_{SU}(i,t))) \tag{7.4}$$

The *max* function is used to ensure that only shortfalls (i.e., situations where demand is greater than capacity) are counted, and ignores situations of surplus beds.

Finally, B_{s_total} is the Total Expected Shortfall over all states and all weeks, which is the value we seek to minimize, and is defined as:

$$B_{s\_total} = \sum_i \sum_t B_s(i,t) \tag{7.5}$$

Thus, the optimization model can be formulated as follows:

$$MIN\ B_{s\_total} \tag{7.6}$$

$$S.T. \quad \sum_i x(i,t) \leq x_{cap}(t) \tag{7.7}$$

$$x(i,t) \geq 0 \tag{7.8}$$

The objective function (7.6) states that we seek to minimize the Total Expected Shortfall of beds over all states and all weeks. The first constraint (7.7) states that the number of beds added for all states i in a region cannot be more than the total regional build capacity for that time period (e.g., per week). Finally, the second constraint (7.8) states that, naturally, we cannot build a negative amount of beds (or stated differently, we would never decide to remove any beds from any locations).

Finally, following a marginal analysis approach (McKenzie 1999), The Expected Usage of Marginal Bed is calculated as:

$$(0.5 * IF(B_{SM}(i,t) > 0, 1, 0)) + (0.25 * IF(B_{SL}(i,t) > 0, 1, 0)) + (0.25 * IF(B_{SU}(i,t) > 0, 1, 0)) \tag{7.9}$$

In other words, these values represent a probability weighted average of whether a shortfall will occur based on mean, lower, and upper estimates of beds needed. Values may equal {1, 0.75, 0.25, 0} and the interpretations are that a marginal bed {will be used, likely to be used, might be used, won't be used}, respectively. Note that the weights of 50%, 25%, and 25% for mean, lower bound, and upper bound, respectively in (7.9) are used as an approximate discretization of the distribution provided, and are not meant to reflect that the data reflect the 25th, 50th, and 75th percentiles. As a short illustrative example, if demand for beds in a given location on a given date is thought to have a 25% chance of being 1,000 (lower bound), a 50% chance of being 1,500 (mean), and a 25% chance of being 2,000 (upper bound), and current capacity is only 500 beds, then the next marginal bed (i.e., an added 501st bed) will be used on that date with 100% probability, as will the 800th bed and the 999th bed, while the 1,000th bed would have a 75% chance of being used as will the all the beds up to the 1,499th, the 1,500th through 1,999th beds have a 25% chance of being used, and the 2,000th bed and above has a 0% chance of being used on that day.

This is the single time period analysis, but in allocating scarce resources over time, the concern is with the expected number of days a bed will be used. So if the demand peaks and then drops so that over a 3 week period the 1,200th bed has a 100% chance of being used for 1 week, a 75% chance of being used for 2 weeks, and a 25% chance of being used for all 3 weeks, the expectation of the number of weeks the bed would be utilized is (100% * 1) + (75% * 2) + (25% * 3) = 3.25, while the 800th bed would have a similar calculation leading to higher expected use. The expected cumulative use of *n-th* marginal bed in this region would be compared (implicitly, in the course of optimization) against the expected use of beds at different levels in other locations competing for the scarce resources.

7.3 Case Study

7.3.1 Data and Assumptions

Forecast were taken from IHME's "COVID-19 Projections" model (IHME COVID-19 Health Service Utilization Forecasting Team 2020). Forecasts were obtained from data available as of 25 March, 2020. The data utilized in the optimization model is a subset of the available data, and includes mean hospital beds needed by day, lower uncertainty bound of hospital beds needed by day, and upper uncertainty bound of hospital beds needed by day. These data were selected for a subset of north-east U.S. states: Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia. The IHME data were provided daily, but we selected a subset of every 7 days (i.e., weekly) over a 13-week time horizon.

Data on Bed Capacity (i.e., how many beds are available) per state are not included in the downloadable file, but can be found on the IHME website[1], and were entered manually into the spreadsheet (Table 7.1).

Additional model assumptions and user-defined inputs include the following:

[1]https://covid19.healthdata.org/.

Table 7.1 Beds Available by State

State	Beds Available
Connecticut	1,738
Delaware	696
District of Columbia	1,093
Maine	1,061
Maryland	3,961
Massachusetts	4,848
New Hampshire	1,018
New Jersey	7,815
New York	13,010
Pennsylvania	14,395
Rhode Island	795
Vermont	533
Virginia	6,581

Source https://covid19.healthdata.org/united-states-of-america

- We assumed that the rate at which new beds can be built per week within the selected region cannot exceed 1,200 beds/week. This rate was estimated based on data reported by the U.S. Army Corps of Engineers[2], where the average construction rate in the study region was approximately 216 beds/week per project, with multiple projects ongoing on any particular day (generally between 4 and 9). Taking six projects per week as a rough mid-point, we arrived at the estimate for 1,200 beds/week.
- We assumed the time lag between the decision to build a bed and when it is completed is 2 weeks.

7.3.2 *Implementation*

The optimization model was implemented in a Microsoft Excel spreadsheet. Since the number of decision variables is large (especially if one chooses to analyze all U. S. states), the default Solver package in Excel is unable to perform the necessary calculations. Given size limitations, the plug-in OpenSolver Advanced[3] was used which can handle large sets of decision variables and allows users to select from a variety of linear and nonlinear solution engines (Mason 2012). While the problem as formulated above is nonlinear, we implemented the spreadsheet in such a way, through the introduction of extra "dummy" decision variables, that the program

[2] https://www.usace.army.mil/Coronavirus/Listing-of-USACE-Contracts-Awarded-for-Alternate-Care-Sites-in-Support-of-COVID-19/.

[3] https://opensolver.org/.

could be solved linearly. The COIN-OR CBC (Linear Solver) engine, included in OpenSolver Advanced, was used.

7.3.3 Optimization Results

The decision variables resulting from the optimization analysis are reported for the 25 March data (Table 7.2). Table 7.2 shows that in the first week (of 25 March), 748 beds are allocated to NJ, whereas 452 are allocated to NY. In the following weeks, beds are allocated to NJ, MA, DE, ME, MD, NH, and VA, with no beds allocated to any states during or after the week of 13 May.

Figures 7.1 and 7.2 show the marginal value of adding an additional bed based on the data set. Figure 7.1 shows the marginal values before the optimization, i.e., with no beds added anywhere, and Fig. 7.2 shows the marginal values post-optimization. In Fig. 7.1, we see that in the first week, a marginal bed will likely be used in NY and VT. Comparison of the pre- and post-optimization values show that adding beds in the specified locations reduces expected shortfalls and therefore the expected use of a marginal bed, especially later in the time horizon (starting around 06 May). The bottom sections of Figs. 7.1 and 7.2 shows the remaining expected value of a marginal bed, which is simply the sum of the expected value of a marginal bed from the current and future weeks. Figure 7.3 plots the cumulative expected use of a marginal bed for each state over time (i.e., the bottom portion of Fig. 7.1). We see that in week 1, New York, Vermont, and New Jersey showed the largest values for the cumulative expected use of a marginal bed. However if we consider the 2 week lag time, and look at week 3, New Jersey, Massachusetts, and New York have the highest values, and in subsequent weeks are surpassed by Delaware, Maine, Maryland and Virginia. From Table 7.2, we see that beds are allocated to New York and New Jersey early, but then the bulk of the beds are allocated Massachusetts, Maryland, and later to Virginia.

7.4 Discussion

Given the urgent need for insights into the problem of where to allocate new beds and other resources, many simplifying assumptions were made following the "scratch modeling" orientation described above (Kaplan 2020). The fact that many simplifying assumptions were made provides ample opportunities for extensions and future research, which are described in this section.

First, a natural extension of the model described here is the consideration other resources besides hospital beds, including ventilators, intensive care beds, and other PPE. While some patients only need beds, others must be placed on ventilators, and therefore shortfalls of both beds and ventilators should be minimized. The IHME

Table 7.2 Optimization Results: Beds Added Based on 25 March Forecast

State	3/25/2020	4/1/2020	4/8/2020	4/15/2020	4/22/2020	4/29/2020	5/6/2020	5/13/2020	5/20/2020	5/27/2020	6/3/2020	6/10/2020	6/17/2020
Connecticut	0	0	0	0	0	0	0	0	0	0	0	0	0
Delaware	0	0	24	0	0	0	0	0	0	0	0	0	0
District of Columbia	0	0	0	0	0	0	0	0	0	0	0	0	0
Maine	0	0	12	0	0	0	0	0	0	0	0	0	0
Maryland	0	0	235	1079	0	0	0	0	0	0	0	0	0
Massachusetts	0	211	921	0	0	0	0	0	0	0	0	0	0
New Hampshire	0	0	8	0	0	0	0	0	0	0	0	0	0
New Jersey	748	989	0	0	0	0	0	0	0	0	0	0	0
New York	452	0	0	0	0	0	0	0	0	0	0	0	0
Pennsylvania	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhode Island	0	0	0	0	0	0	0	0	0	0	0	0	0
Vermont	0	0	0	0	0	0	0	0	0	0	0	0	0
Virginia	0	0	0	121	1200	1200	1200	0	0	0	0	0	0

1 Will be used | 0.75 Likely to be used | 0.25 Might be used | 0 Won't be used

Expected usage of marginal bed	3/25/2020	4/1/2020	4/8/2020	4/15/2020	4/22/2020	4/29/2020	5/6/2020	5/13/2020	5/20/2020	5/27/2020	6/3/2020	6/10/2020	6/17/2020
Connecticut	-	0.75	0.75	0.75	0.25	0.25	-	-	-	-	-	-	-
Delaware	-	-	-	0.25	0.75	0.25	0.25	-	-	-	-	-	-
District of Columbia	-	-	-	-	-	-	-	-	-	-	-	-	-
Maine	-	-	-	0.25	0.75	0.25	-	-	-	-	-	-	-
Maryland	-	-	0.25	0.25	0.25	0.25	0.25	0.25	0.25	-	-	-	-
Massachusetts	-	0.25	0.75	0.75	0.75	0.25	-	-	-	-	-	-	-
New Hampshire	-	-	-	0.25	0.25	0.25	0.25	-	-	-	-	-	-
New Jersey	-	0.75	1.00	0.75	0.75	0.25	-	-	-	-	-	-	-
New York	0.75	1.00	1.00	0.75	0.25	0.25	-	-	-	-	-	-	-
Pennsylvania	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhode Island	-	-	-	-	0.25	0.25	-	-	-	-	-	-	-
Vermont	0.75	1.00	1.00	0.75	0.25	-	-	-	-	-	-	-	-
Virginia	-	-	-	-	-	0.25	0.25	0.25	0.25	-	-	-	-
Remaining expected usage of marginal bed	3/25/2020	4/1/2020	4/8/2020	4/15/2020	4/22/2020	4/29/2020	5/6/2020	5/13/2020	5/20/2020	5/27/2020	6/3/2020	6/10/2020	6/17/2020
Connecticut	2.75	2.75	2.00	1.25	0.50	0.25	-	-	-	-	-	-	-
Delaware	1.50	1.50	1.50	1.50	1.25	0.50	0.25	-	-	-	-	-	-
District of Columbia	-	-	-	-	-	-	-	-	-	-	-	-	-
Maine	1.25	1.25	1.25	1.25	1.00	0.25	-	-	-	-	-	-	-
Maryland	1.75	1.75	1.75	1.50	1.25	1.00	0.75	0.50	0.25	-	-	-	-
Massachusetts	2.75	2.75	2.50	1.75	1.00	0.25	-	-	-	-	-	-	-
New Hampshire	1.00	1.00	1.00	1.00	0.75	0.50	0.25	-	-	-	-	-	-
New Jersey	3.50	3.50	2.75	1.75	1.00	0.25	-	-	-	-	-	-	-
New York	4.00	3.25	2.25	1.25	0.50	0.25	-	-	-	-	-	-	-
Pennsylvania	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhode Island	0.50	0.50	0.50	0.50	0.50	0.25	-	-	-	-	-	-	-
Vermont	3.75	3.00	2.00	1.00	0.25	-	-	-	-	-	-	-	-
Virginia	1.00	1.00	1.00	1.00	1.00	1.00	0.75	0.50	0.25	-	-	-	-

Fig. 7.1 Marginal analysis of beds based on 25 March data (before optimization)

1 Will be used | 0.75 Likely to be used | 0.25 Might be used | 0 Won't be used

Expected usage of marginal bed	3/25/2020	4/1/2020	4/8/2020	4/15/2020	4/22/2020	4/29/2020	5/6/2020	5/13/2020	5/20/2020	5/27/2020	6/3/2020	6/10/2020	6/17/2020
Connecticut	-	0.75	0.75	0.75	0.25	0.25	-	-	-	-	-	-	-
Delaware	-	-	-	0.25	0.25	0.25	-	-	-	-	-	-	-
District of Columbia	-	-	-	-	-	-	-	-	-	-	-	-	-
Maine	-	-	-	0.25	0.25	0.25	-	-	-	-	-	-	-
Maryland	-	-	0.25	0.25	0.25	0.25	-	-	-	-	-	-	-
Massachusetts	-	0.25	0.75	0.75	0.75	0.25	-	-	-	-	-	-	-
New Hampshire	-	-	-	0.25	0.25	0.25	-	-	-	-	-	-	-
New Jersey	-	0.75	1.00	0.75	0.25	0.25	-	-	-	-	-	-	-
New York	0.75	1.00	1.00	0.75	0.25	0.25	-	-	-	-	-	-	-
Pennsylvania	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhode Island	-	-	-	-	0.25	0.25	-	-	-	-	-	-	-
Vermont	0.75	1.00	1.00	0.75	0.25	-	-	-	-	-	-	-	-
Virginia	-	-	-	-	-	0.25	0.25	-	-	-	-	-	-
Remaining expected usage of marginal bed	3/25/2020	4/1/2020	4/8/2020	4/15/2020	4/22/2020	4/29/2020	5/6/2020	5/13/2020	5/20/2020	5/27/2020	6/3/2020	6/10/2020	6/17/2020
Connecticut	2.75	2.75	2.00	1.25	0.50	0.25	-	-	-	-	-	-	-
Delaware	0.75	0.75	0.75	0.75	0.50	0.25	-	-	-	-	-	-	-
District of Columbia	-	-	-	-	-	-	-	-	-	-	-	-	-
Maine	0.75	0.75	0.75	0.75	0.50	0.25	-	-	-	-	-	-	-
Maryland	1.00	1.00	1.00	0.75	0.50	0.25	-	-	-	-	-	-	-
Massachusetts	2.75	2.75	2.50	1.75	1.00	0.25	-	-	-	-	-	-	-
New Hampshire	0.75	0.75	0.75	0.75	0.50	0.25	-	-	-	-	-	-	-
New Jersey	3.00	3.00	2.25	1.25	0.50	0.25	-	-	-	-	-	-	-
New York	4.00	3.25	2.25	1.25	0.50	0.25	-	-	-	-	-	-	-
Pennsylvania	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhode Island	0.50	0.50	0.50	0.50	0.50	0.25	-	-	-	-	-	-	-
Vermont	3.75	3.00	2.00	1.00	0.25	-	-	-	-	-	-	-	-
Virginia	0.50	0.50	0.50	0.50	0.50	0.50	0.25	-	-	-	-	-	-

Fig. 7.2 Marginal analysis of beds based on 25 March data (after optimization)

epidemiological model used as a data source provides demand forecasts of hospital beds, ICU beds, and ventilators.

An important consideration is maintaining appropriate staffing levels, including doctors, nurses, and support staff. Even with enough beds and ventilators, a shortage in health care personnel can adversely affect patient outcomes. The U.S. Centers for Disease Control and Prevention (2020) outlined strategies for mitigating healthcare personnel shortages. Maintaining appropriate staffing ratios across regions could be added as a model constraint.

Another area for investigation is in better understanding how beds are used, and therefore how many will be needed. For example, given the cleaning requirements following a patient discharge or death, there may be a percentage of beds which are unused at any point in time. Additionally, as doctors continue to learn how to treat

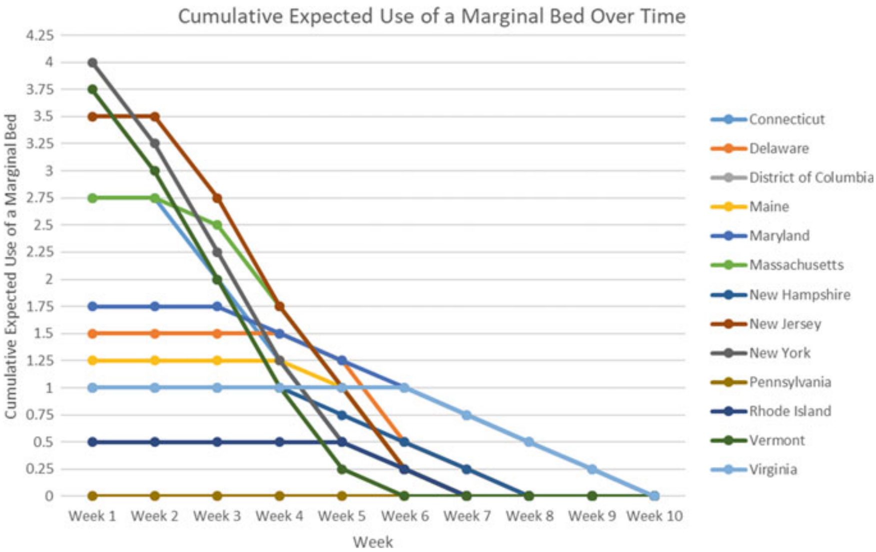

Fig. 7.3 Cumulative expected use of a marginal bed, before optimization

hospitalized patients more effectively and efficiently, bed needs will change. Moreover, as mentioned above, we assumed that beds would never be removed from a location. However, it is possible that beds or ventilators could be relocated. All of these are factors which could be investigated within the existing modeling framework.

A further extension is to link the analysis with geographical modeling tools such as GIS (Yatsalo et al. 2016). This would allow analysts to investigate how close facilities are to other hospitals. A natural extension of the model is to consider different geographical scales (e.g., county-level) or metropolitan areas.

Finally, several of the data inputs can be further refined, such as the rate at which beds can be built per week. Subject matter experts will need to be consulted to provide these inputs. These rates might be different across locations/regions depending on a number of factors. In the absence of well-documented data, ranges can be provided and sensitivity analysis performed. Another input consideration is the 0.25-0.5-0.25 probability distribution for expected bed shortfall. Other distributions and parameterizations could be used, such as 0.3-0.4-0.3 (Hurst et al. 2000). Finally, non-linear loss functions may also be investigated.

7.5 Conclusions

In this chapter, we have proposed an approach for identifying “hot spots” where epidemiological models predict the greatest shortfalls in hospital bed capacity. Using an optimization model, we demonstrated the ability to schedule and allocate scarce healthcare resources in specific locations, adding beds such that the total expected shortfall will be minimized. This modeling approach can be used as part of a broader public health strategy, comprising a number of key capabilities. A strategic and proactive allocation of hospital resources, including bed capacity, can aid in an overall effort to increase the resilience of the healthcare system to systemic shocks (Hynes et al. 2020). However, a value-based optimization approach is not limited to the allocation of healthcare resources and can be applied to many different types of disaster response efforts, especially those which continue over a protracted time frame. Disaster response efforts in general could benefit from such resource allocation approaches, especially when used in conjunction with probabilistic forecast models.

While new information about the disease continues to be generated and disseminated by researchers, healthcare practitioners, health agencies, etc., the decision making environment continues to be highly uncertain and dynamic. Public health decisions must be made based on the best current understanding of rapidly evolving datasets and forecasts (Uhlig et al. 2020). However, forecasts can (and do) change, which requires a dynamic and flexible approach to modeling and decision making. With a model like the one described in this chapter, changing forecasts may require iteratively running the model to optimize allocation decisions in the short term, while updating both the forecasts and future allocations regularly as new information becomes available.

Acknowledgements This work was supported by the USACE FLEX Program. The opinions expressed herein are those of the authors alone, and not necessarily of their affiliated institutions.

Disclaimer: The views and opinions expressed in this article are those of the individual authors and not those of the U.S. Army or other sponsor organizations.

References

Billingham S, Widrick R, Edwards NJ, Klaus SA (2020) COVID-19 (SARS-CoV-2) ventilator resource management using a network optimization model and predictive system demand. medRxiv preprint https://doi.org/10.1101/2020.05.26.20113886

Croxton KL, Lambert DM, García-Dastugue SJ, Rogers DS (2002) The demand management process. Int J Logistics Manage 13(2):51–66

Eriksson CO, Stoner RC, Eden KB, Newgard CD, Guise JM (2017) The association between hospital capacity strain and inpatient outcomes in highly developed countries: a systematic review. J Gen Intern Med 32(6):686–696

Golan MS, Jernegan LH, Linkov I (2020) Trends and applications of resilience analytics in supply chain modeling: systematic literature review in the context of the COVID-19 pandemic. Environ Syst Decisions 40(2):222–243

Hurst A, Brown GC, Swanson RI (2000) Swanson's 30-40-30 rule. AAPG Bull 84(12):1883–1891

Hynes W, Trump B, Love P, Linkov I (2020) Bouncing forward: a resilience approach to dealing with COVID-19 and future systemic shocks. Environ Syst Decisions 40(2):174–184

IHME COVID-19 Health Service Utilization Forecasting Team (2020) Forecasting the impact of the first wave of the COVID-19 pandemic on hospital demand and deaths for the USA and European Economic Area countries. medRxiv preprint https://doi.org/10.1101/2020.04.21.20074732

Kaplan EH (2020) COVID-19 scratch models to support local decisions. Manuf Serv Oper Manage 22(4):645–655

Laventhal N, Basak R, Dell ML et al (2020) The ethics of creating a resource allocation strategy during the COVID-19 pandemic. Pediatrics 146(1):

Lippi G, Sanchis-Gomar F, Henry BM (2020) Coronavirus disease 2019 (COVID-19): the portrait of a perfect storm. Ann Transl Med 8(7):497

Manca D, Caldiroli D, Storti E (2020) A simplified math approach to predict ICU beds and mortality rate for hospital emergency planning under Covid-19 pandemic. Comput Chem Eng 140:

Mason AJ (2012) OpenSolver: an open source add-into solve linear and integer progammes in Excel. In: Klatte D, Lüthi HJ, Schmedders K (eds) Operations research proceedings 2011. Springer, Berlin, Heidelberg, pp 401–406

McKenzie RB (1999) Marginal analysis in economics. In: Dorf RC (ed) The technology management handbook. CRC Press: Boca Raton, FL

Mehrotra S, Rahimian H, Barah M, Luo F, Schantz K (2020) A model of supply-chain decisions for resource sharing with an application to ventilator allocation to combat COVID-19. Naval Res Logistics 67(5):303–320

Meyer GS, Blanchfield BB, Bohmer RMJ, Mountford J, Vanderwagen WC (2020) Alternative care sites for the Covid-19 pandemic: the early U.S. and U.K. experience. NEJM Catalyst. https://doi.org/10.1056/cat.20.0224

Santini A (2020) Optimising the assignment of swabs and reagents for PCR testing during a viral epidemic. http://www.optimization-online.org/DB_FILE/2020/05/7775.pdf

Uhlig S, Nichani K, Uhlig C, Simon K (2020) Modeling projections for COVID-19 pandemic by combining epidemiological, statistical, and neural network approaches. medRxiv preprint https://doi.org/10.1101/2020.04.17.20059535

U.S. Centers for Disease Control and Prevention (2020) Strategies to Mitigate Healthcare Personnel Staffing Shortages. https://www.cdc.gov/coronavirus/2019-ncov/hcp/mitigating-staff-shortages.html

Yatsalo B, Gritsuk S, Sullivan T, Trump BD, Linkov I (2016) Multi-criteria risk management with the use of DecernsMCDA: methods and case studies. Environ Syst Decis 36(3):266–276

Zaza S, Koonin LM, Ajao A, Nystrom SV, Branson R, Bray B, Iademarco MF (2016) A conceptual framework for allocation of federally stockpiled ventilators during large-scale emergencies. Health Secur 14(1):1–6

Chapter 8
Overview of Preventive Measures and Good Governance Policies to Mitigate the COVID-19 Outbreak Curve in Brunei

Malai Zeiti Binti Sheikh Abdul Hamid and Rama Rao Karri

Abstract The COVID-19 outbreak has completely devastated the economies of the major countries and disrupted many people's lives. Despite the huge outbreak and devastation brought by the pandemic, there are a growing number of countries that has been able to control the spread of the outbreak, signifying a strong recovery. Brunei is one of the few countries that has been able to control the outbreak and "flatten the curve". This paper explores the rate of growth of COVID-19 cases in Brunei and highlights resilient actions that have been taken to mitigate further infection and contain outbreak nationally. The Sultanate of Brunei has taken various timely actions to minimise the risk of further outbreak and implemented serious measures to support any infected patients in the country. Brunei is also one of the few countries in the world to have contained the spread of the infection with no newly infected local cases recorded for nearly 6 months. This paper also takes into account the new COVID-19 cases that were imported cases from returning travellers to Brunei travellers and how the authorities handled these new cases. The current observations in this paper thus serves as a reference for notable policies to contain future pandemics and in order to achieve a sustainable society.

Keywords COVID-19 · Preventive and mitigation measures · Flatten the curve · Risk and resilience · Practices and interventions

Both authors contributed equally.

M. Z. B. S. A. Hamid
Centre for Communication, Teaching & Learning (CCTL), Universiti Teknologi Brunei, Bandar Seri Begawan BE1410, Brunei Darussalam

M. Z. B. S. A. Hamid · R. R. Karri (✉)
Wellness Research Thrust, Universiti Teknologi Brunei, Bandar Seri Begawan BE1410, Brunei Darussalam
e-mail: kramarao.iitd@gmail.com

R. R. Karri
Faculty of Engineering, Universiti Teknologi Brunei, Bandar Seri Begawan BE1410, Brunei

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_8

8.1 Introduction

The SARS-CoV-2 (COVID-19) virus was first identified in Wuhan, China in December 2020 and spread rapidly to nearly every country in the world. On January 22, 2020, it was reported that as many as 534 COVID-19 cases and 17 deaths were reported around the world. This representation composed of countries Asia including China (526 cases) and other Asian countries including Taiwan (1 case), Japan (1 case), South Korea (1 case) and Thailand (4 cases), while the United States (1 case) represented the only non-Asian country. The COVID-19 pandemic has spread across the world and escalated to a total of over 45 million COVID-19 cases with nearly one million deaths worldwide (as of 28 October, 2020). The most affected country in the world with the highest number of COVID-19 cases is the United States with a total of 9.3 million COVID-19 cases and over 230,000 deaths representing about 25% of the total world infected population. Countries such as Italy, Germany and France in Europe had recorded up to 7,500 COVID-19 cases a day but managed to reduce the spread further. Today, United States continues to show persistent growth as high as 75,000 COVID-19 cases a day, while many countries have managed to show a bending and flattening of the curve over time (Worldometers, 2020).

Asians nations such as Hong Kong, South Korea, Singapore and Taiwan have populations of millions of people and received media attention on how they managed the control the during the outbreak (Pung 2020; Wong et al. 2020). These countries had shown a sharp increase in COVID-19 cases since the appearance of their first cases. Among these nations, for example, South Korea reported a rapid rise of new cases, with as high as 909 in a single day (Shim 2020), while some countries have reduced the number of new cases to under fifty cases per day and projections of a complete recovery. The reduction of cases in Taiwan, New Zealand and Iceland, for example, have been praised globally for their strong and efficient responses in handling the pandemic (Wu et al. 2020; Cousins 2020; Baker et al. 2020; Fouda 2020). Although COVID-19 infections had peaked as high as 99 cases per day but through the respective government's efforts, the infected cases have reduced significantly, with daily COVID-19 cases now ranging from 0 to 5 cases only.

In Asia, Brunei is one country has been able to handle the outbreak efficiently. Brunei is one of the 10 countries in Southeast Asia that make up the Association of Southeast Asian Nations (ASEAN) and sharing borders with Malaysia and Indonesia. Brunei is well known for its large oil and gas reserves. It is also the 3rd largest oil producer in Southeast Asia and the 9th largest liquefied natural gas producer in the world. Brunei also represents one of the highest GDPs per capita and human development indexes (HDI) in the world.

Although there are new imported cases entering Brunei since August 8, 2020, the number of infected cases locally remained at zero. As of 28 October 2020, there have been 143 recovered cases, and no new local cases were recorded. However, there are 7 new imported cases from overseas with 1 current active case undergoing treatment. To date, it has been 173 days now since 6 May 2020 from the last known local case of COVID19 in Brunei.

The first **local** COVID-19 case in Brunei was recorded on 9 March 2020, when a man returned from a religious gathering held in Malaysia in late February 2020 in which over 16,000 people attended from around the world. The first infected Brunei case was one of the 81 Bruneians, who had participated in the event.

The new imported cases were first recorded on August 7, 2020 from a returning male traveller returning to Brunei from Yemen. On August 19, 2020 a second imported case was identified from a woman arriving via Kuala Lumpur from the Middle East. In the same month, a third imported case was reported on August 25, 2020 from a returning male traveller via Kuala Lumpur from India. The fourth imported case was reported on September, 3, 2020 from a man returning to Brunei via Kuala Lumpur from Indonesia. On September 24, 2020, a fifth imported case was reported from a male traveller who arrived into Brunei from India. On October 14, 2020, a sixth imported case was reported from a female traveller who arrived to Brunei from Nepal. The seventh imported case was reported from man who returned to Brunei from Kuala Lumpur, Malaysia on October 16, 2020. As of October 27, 2020, there are a total of 7 imported cases who have recovered with 1 active case remaining, who is undergoing treatment at the National Isolation Centre. The total number of infected cases now stayed to 148 cases in total, which included the 7 new imported cases since August 7, 2020.

Brunei is currently in the last phase of de-escalation, where the country is returning back to normal, but with social distancing and other precautionary measures well in place Wong, et al. (2020), Thunström (2020). Accordingly, it is important to note that smaller number of new cases, with increased number of recoveries in any country is indicative of the stringent leadership of any government. Governments worldwide have implemented various precautionary measures including travel bans, school closures, lockdowns, restricted public transportation and closing of public venues, and banning of mass gatherings. In addition, public advisory measures such as keeping good hygiene, the use of face masks, proper sanitization and more importantly, keeping social distancing are crucial in combating the pandemic. Just as important, credit should be given to the people in their countries for adhering to the policies and guidelines that have been implemented by their governments.

8.2 Methodology

8.2.1 Study Area

The research paper reviews the policy responses and actions taken by the Government of Brunei, a country on the island of Borneo, with a population of approximately 437,000. The implementation of actions and measures were compared with other countries around the world and countries in Southeast Asia to enable for better understanding of the effect of policies. Any reference to countries in Southeast Asia specifically refers to the official 10-member countries in the Association of Southeast Asian Nations (ASEAN). The other countries compare to Brunei are among the 215 countries and territories listed on WorldOmeter (Worldometers, 2020).

8.2.2 Data Collection

In this study, data was collected from multiple sources, mainly from:

- Over 20 daily press releases obtained from the Brunei Ministry of Health website
- The "Our World in Data" website that provides up to date statistics and research data on the Coronavirus Pandemic (COVID-19) (Roser et al. 2020)
- WorldOmeter website that provides daily statistics on all COVID-19 updates for a list of countries and territories around the world (Worldometers, 2020)

8.2.3 Flattening the Curve

According to the World Health Organization (WHO) "the flattening of the curve" is described as: "A flatter curve is created by a more gradual increase in the number of cases per day and a more gradual decrease. Over a long period of time, the number of people infected might be around the same, but the difference is the number of cases that occur each day" (WHO 2020). As shown in Fig. 8.1, the goal of flattening the curve is to slow down the infections of COVID19 so that the cases do not peak at the same time at any one time.

In Brunei, the curve has completely flattened with zero new cases over the last 175 days, as of October 28, 2020. With the implementation of vigorous preventive measures and national policies, Brunei has not seen any new local cases for over 3 months and is currently in the final stages of a national de-escalation phase. Brunei continues to undergo de-escalation phases in stages and the government continues to implement strict precautionary measures and social distancing despite having seen no resurgence or any new local infected cases over the past 3 months.

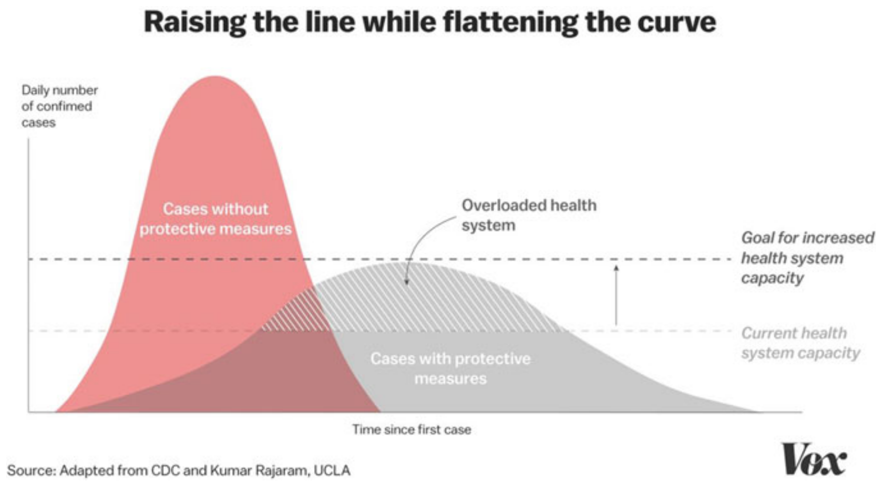

Fig. 8.1 Schematic representation of raising the line while flattening the curve (Adapted from Eliza et al. 2020)

8.3 Results and Discussion

The following compilation of data attempts to highlight the efforts and actions taken by the government of Brunei that help to provide an explanation of how Brunei has been highly successful in suppressing the COVID-19 outbreak in the country.

8.3.1 The Outbreak of COVID-19 Cases in Brunei

Brunei has recorded its first COVID-19 case on March 9, 2020 in the Tutong district, one of the 4 districts in the country. The Ministry of Health confirmed that the first case is a 53-year-old male who had come back from a Tablighi (Muslim congregation) in Kuala Lumpur, Malaysia on March 3, 2020. The patient began to show the symptoms on March 7, 2020 and was eventually moved to the National Isolation Centre in Tutong for treatment. On March 10, 2020, the Ministry of Health reported five new cases, bringing the total to six. These five persons were close contacts of the first case and were isolated for treatment. On the next day (March 11, 2020), the Health Ministry reported another five new cases, bringing the total number to 11. Three of these individuals had also attended the Tablighi in Kuala Lumpur on March 3, 2020. Among Brunei's first 50 cases, 45 were related to the congregation, and later the number of cases has risen with many clusters as shown in Fig. 8.2. After the outset of the first case, COVID-19 has spread across Brunei over a period of exactly 175 days in which its last case was reported on May 7, 2020 with a total of 141 local infected cases.

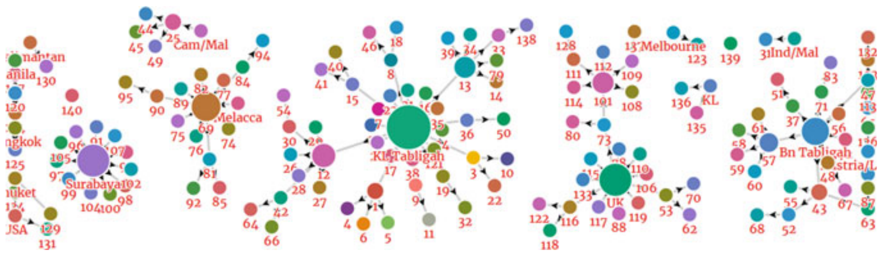

Fig. 8.2 Schematic representation of the spread of COVID-19 cases in Brunei and the formation of clusters

8.3.2 *Daily and Total Confirmed COVID-19 Cases in Brunei*

After reporting the first case on March 9, 2020, the number of cases increased drastically within a short period of three weeks (see Fig. 8.3a). After the last case reported on May 7, 2020, there were no new cases reported. As of October 28, 2020, Brunei is reported to have had no new local cases for just over three months (about 175 days). The highest number of COVID-19 cases in Brunei was reported as fourteen cases in a single day on March 14, 2020, within the first week after the first reported case on March 9, 2020. To date, there have been a total of three COVID-19 related deaths (see Fig. 8.3b) in Brunei, and the case fatality rate (CFR) stands at 2.13%.

8.3.3 *Timeline of Events and Actions Taken by the Brunei Government*

On January 4, 2020, the World Health Organization reported on social media that there was a cluster of pneumonia cases in Wuhan, Hubei province, China. As shown in Table 8.1, the Government of Brunei, specifically the Brunei Ministry of Health (MOH) acted as early as January 6, 2020 making a public notification to the general public of Brunei regarding the severity of pneumonia-like cases in Wuhan, China. By January 24, 2020, MOH has taken numerous proactive measures and established a Standard Operating Procedure (SOP) for potential suspected COVID-19 cases by introducing self-isolation policies for flights returning from China, implementing travel bans and advising the public to avoid unnecessary travel.

Despite the early precautionary measures in January 2020, Brunei recorded its first COVID-19 case on March 9, 2020. After the outset of the first case, the number of COVID-19 cases had grown and reached to 127 cases within three weeks from the first reported case (Wong 2020). However, during these three weeks, the MOH

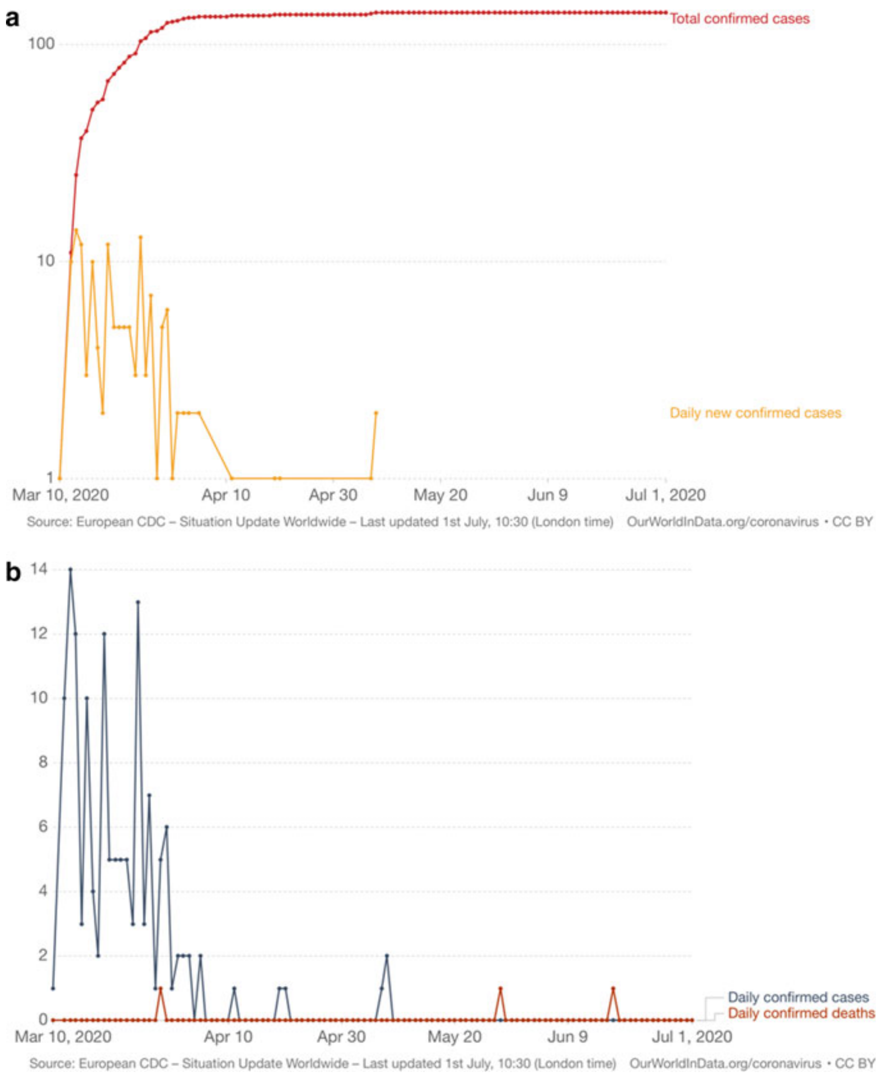

Fig. 8.3 COVID-19 cases in Brunei between 9 March–2 July 2020 **a** Daily new confirmed cases and **b** Daily confirmed cases and deaths reported

took immediate steps to implement and promote social distancing measures and guidelines to the public. At the same time, the MOH suspended all activities and events that had the potential for large groups and mass gatherings within the country, including weddings, sports tournaments and national events. Close contacts and family members of the infected patients were identified, tested and sent for self-isolation.

Table 8.1 Timeline of events and actions taken by the Brunei Government during the COVID-19 outbreak in Brunei (January 6, 2020–June 30, 2020)

Date	Actions and initiatives taken by the government of Brunei from the onset of the COVID-19 in light of increased number of infected cases	Total no. of cases
6 Jan	Ministry of Health (MOH) makes a press release to the Brunei public of a cluster of severe pneumonia cases in Wuhan City, China	0
24 Jan	Established standard operating procedure (SOP) for imported patients suspected of COVID-19	0
4 Feb	MOH introduced self-isolation policy for citizens returning from China to Brunei	0
5 Mar	(1) MOH issues Visitor Ban from Iran, Italy and China, who are restricted from entering Brunei (2) MOH advises the public to avoid unnecessary travel to other countries	0
9 Mar	Detection of the first COVID-19 case in Brunei	1
11 Mar	MOH notifies the public that Quarantine Orders are issued to relevant suspected cases MOH conducts contact tracing among the public	11
12 Mar	(1) The relevant authorities amend the Infectious Disease Act (Chapter 204) and its regulations to combat the spread of COVID-19 (2) MOH notifies the public that any latest COVID-19 related developments will be shared on the official MOH website (3) MOH announces the Health Advice Helpline (24 h) to the public	25
13 Mar	(1) MOH prohibits all types of mass gathering in the country (2) His Majesty, the Sultan of Brunei announces to call off national celebrations (3) MOH promotes awareness to the public on social distancing measures	37
16 Mar	MOH issues the travel ban to restrict all citizens and residents from leaving the country	54
17 Mar	(1) MOH notifies the public that the use of public facilities and venues such as museums, bowling centres, gymnasiums, cinemas will be suspended (2) MOH extends the Visitor Ban to all countries in Europe, and the UK	56
18 Mar	(1) MOH notifies the public that Government of Brunei is implementing the Business Continuity Plan around the outbreak (2) The E-Government National Centre (EGNC) and the Ministry of Transport and Infocommunication (MTIC) announce that the messaging application, Telegram will be used to disseminate information and advice to the public regarding COVID-19 (3) The Ministry of Home Affairs (MOHA) prohibits dine-in at all food service providers including restaurants, café and food courts	68
19 Mar	The Ministry of Culture, Youth and Sports (MCYS) established the Ad-Hoc 'Committee of Youth Volunteers' to bring volunteers and support the efforts of the MOH	73

(continued)

Table 8.1 (continued)

Date	Actions and initiatives taken by the government of Brunei from the onset of the COVID-19 in light of increased number of infected cases	Total no. of cases
20 Mar	MOH implements a 14-day mandatory isolation in designated accommodation for all passengers arriving in Brunei	78
21 Mar	MOH announces the construction of the Molecular Diagnostic Unit (MDU) for Respiratory Viruses, a new virology laboratory, dedicated to the analysis of COVID-19 tests	83
23 Mar	MOHA prohibits all foreign nationals from entering Brunei via land, sea or air	91
27 Mar	The construction of the new National Isolation Centre building in the Tutong district began	115
30 Mar	MOH announces that construction of the MDU virology laboratory has been completed	127
1 Apr	The MDU virology laboratory begins its operations	131
23 Apr	The construction of the new National Isolation Centre building is completed	138
25 Apr	The new National Isolation Centre building began its operation	138
7 May	The last COVID-19 local case(s) in Brunei remained at 141 cases	141
14 May	(1) MOH launches the contract tracing application, `BruHealth' for contact tracing to the public (2) MOH announces to the public on the reduction of social distancing measures	141
21 May	MOH issues guidelines to the public on social distancing for celebrating national events	141
28 May	MOH launches the `PremiseScan' application, which is designed for business owners to scan customers upon entry and exit	141
18 Jun	MOH announces additional reduction to social distancing measures	141
23 Jun	MOH allows reduces air travel restrictions to travellers who need to leave the country	141
30 Jun	MOH conducted a monitoring and enforcement patrol operation on business premises to ensure that directives from the MOH are followed	141

In every effort to restrict any growth of imported cases, the Brunei Ministry of Transport and Info-communications (MTIC) imposed international travel bans that restricted entry to and from Brunei via air, sea and land border. Additionally, to reduce the potential spread within student communities, the Ministry of Education (MOE) announced the closure of schools and universities and placed a restriction on student and teacher gatherings. To facilitate the continuation of education in the country, the MOE implemented measures for all students to study from home through online education and other suitable means. The Ministry of Culture Youth and Sports (MCYS) established a dedicated Youth Volunteer committee to provide additional support to MOH activities in suppressing the COVID-19 outbreak across the country. The Ministry of Home Affairs (MOHA) also provided advisories to the public to observe and practice social distancing guidelines and implemented strict monitoring measures such as temperature screening, provision of hand sanitizers and limiting the number of customers entering public places and commercial shopping malls.

Other significant efforts by the Brunei government include the construction of the National Isolation Centre building, which was completed in one month, after the first case reported.. A new Molecular Diagnostic Unit virology laboratory was also constructed within ten days. Both buildings were completed and operational by April 25, 2020. The total number of COVID-19 cases peaked at 141 cases as of May 7, 2020. As there were no new cases reported, Brunei was able to progress to a de-escalation phase while maintaining strict forms of both preventive and social distancing measures.

In order to implement contact tracing measures, the Brunei government also introduced two mobile phone applications called “BruHealth” and “PremiseScan” for the general public which assisted in monitoring the locations of phone users (see Fig. 8.4). These applications had many features, including contact tracing that was able to record the entry and exit of users at any premise (shops, offices, commercial outlets, eateries, etc.). In addition, these applications provided daily updates on COVID-19 cases locally and globally and to keep track of every person entering restricted public facilities such as mosques, swimming pools and gyms.

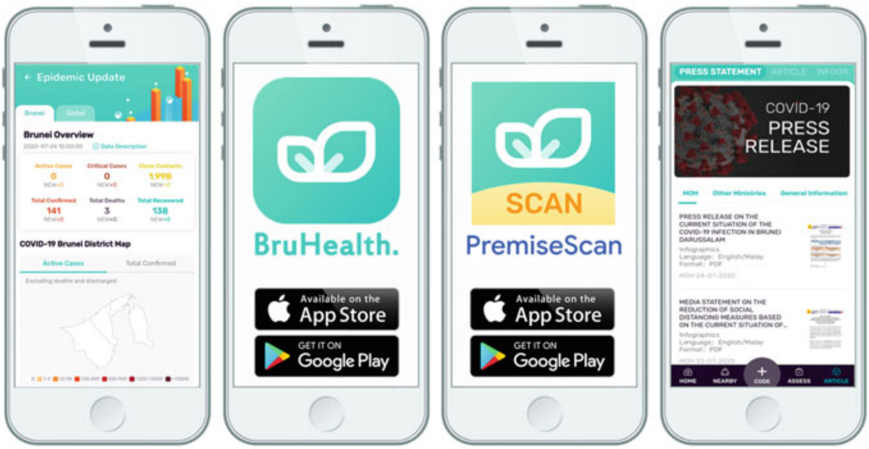

Fig. 8.4 BruHealth and PremiseScan app

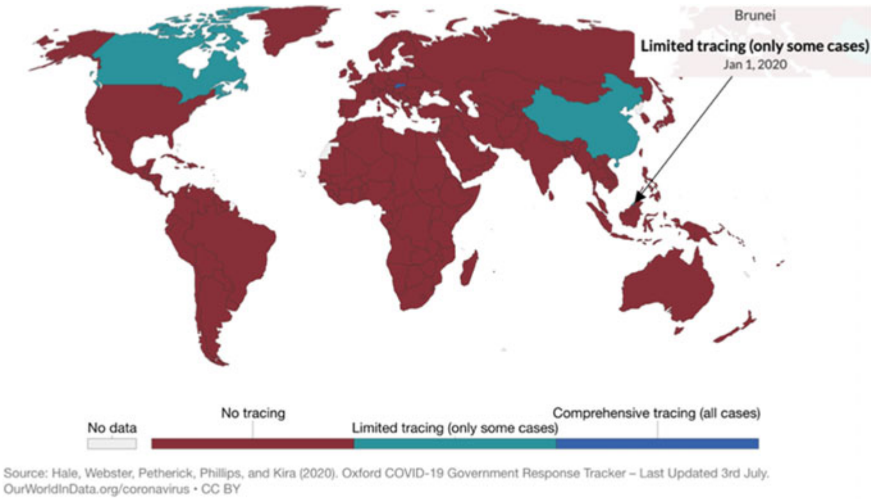

Fig. 8.5 Depiction of countries showing contact tracing for COVID-19 as on January 1, 2020

8.3.4 Contract Tracing and Public Information Campaigns

As shown in Fig. 8.5, Brunei was reported to be one of four countries (China, Canada, Brunei and Slovakia) in the world to have established contact tracing measures or guidelines as early as January 1, 2020. This was a significant indicator of Brunei's fast and proactive action to control the outbreak.

As early as January 6, 2020, Brunei is shown to be one of only five countries in the world including China, Botswana, Mongolia and Indonesia to have implemented public information campaign on the COVID-19 pandemic (see Fig. 8.6). Brunei was also one of only two countries with Mongolia to have conducted serious coordinated information campaign at government level. In contrast, some major countries in the world including Australia, India, France, Brazil and Saudi Arabia had only begun on take serious actions in their respective countries on early February 2020 and to implement official public information campaign on the COVID-19 outbreak. In retrospect, it was only on January 30, 2020, that the World Health Organization (WHO) had confirmed that the outbreak constituted a Public Health Emergency of International Concern (PHEIC).

8.3.5 International Travel Controls

Figure 8.7 depicts countries that have implemented a restriction on international travel controls as on January 30, 2020. The legend depicts 6 codes with Code 0 representing no data and Code 6 representing a total border closure (highest level).

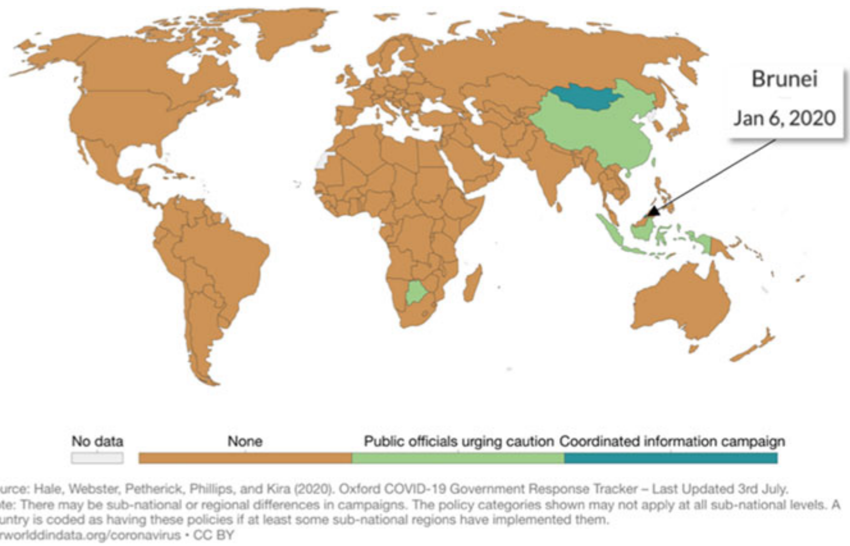

Fig. 8.6 Public information campaigns on the COVID-19 pandemic on January 6, 2020

As of January 30, 2020, Brunei was one of seven countries (Taiwan, Russia, Italy, Czech Republic, Malaysia, Papua New Guinea) in the world to have implemented a Code 5 travel restriction, which is a “Ban on high-risk regions” international travel control measure. It should also be highlighted that 4 of these 7 countries had recorded their first COVID-19 case in the month of January 2020; while Brunei, Czech Republic and Papua New Guinea for example, only recorded their first case in the month of March 2020.

At the same time, some countries like France, Canada, India and Japan have implemented a screening policy (Code 2), while some other countries such as the United States, China, South Korea and Thailand did not have any travel measures (Code 1) in place despite already having recorded cases in their respective countries (see Fig. 8.7). The implementation of an international travel control and ban as early as January 2020 is another indicator of the Brunei government’s swift action, rather than use the ‘wait and see approach’. On 24 March 2020, the Brunei government increased an internal travel restrictions to Code 6, that is, a total border closure during the peak of COVID-19 cases in Brunei (Wong et al. 2020). This move was imposed to ensure that all air, sea and land travel was completely restricted to reduce and control further spread of the outbreak.

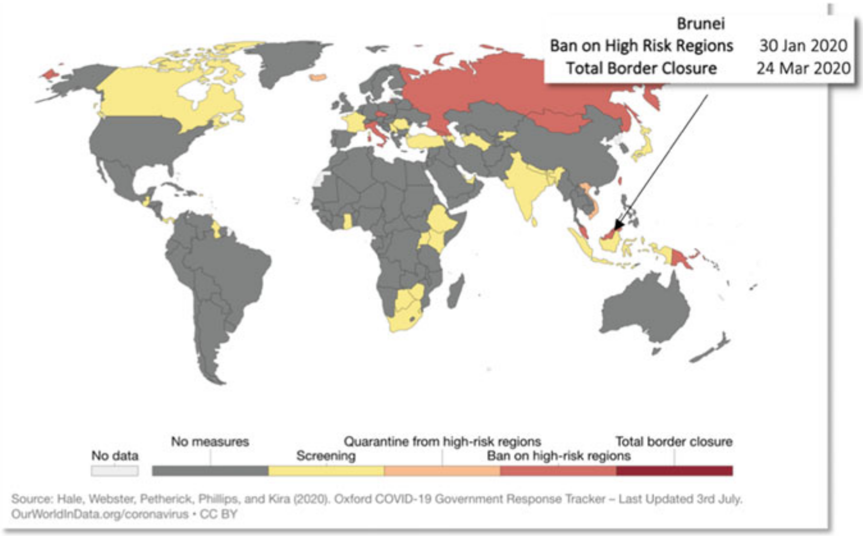

Fig. 8.7 International travel controls during the COVID-19 pandemic as on January 30, 2020

8.3.6 Testing Policies

Members of the public who have shown common symptoms to those infected with coronavirus, as described by the Brunei MOH, were advised to seek medical attention (Wong 2020). As shown in Fig. 8.8, the world chart depicts countries that have implemented testing policies. The legend depicts different testing 4 policies, with Code 0 representing No testing and Code 4 represents Open Public Testing (highest level). The range of testing range can be translated as Code 1 (No testing policy), Code 2 (Testing anyone who exhibit symptoms and is of high risk such as travellers returning from overseas, and to have come in contact with confirmed cases; Code 3 (Testing anyone with symptoms) and Code 4 (Open public testing—this includes tests using a drive-through approach and includes testing for those who are asymptomatic).

Brunei was also one of the few countries to implement a Code 3 testing policy immediately on the same day that the first COVID-19 case was recorded on March 9, 2020. Despite the initial sudden growth of COVID-19 cases in Brunei within the first 3 weeks, immediate precautionary measures and immediate actions were taken through a combination of testing, quarantines and self-isolation, thus preventing any need for further escalation to Code 4 (open public testing).

In terms of implementing testing policy, Brunei actions are comparable to other highly technologically advanced countries with a large number of cases such as the United States and the United Kingdom. Since early March 2020, it is expected that such policy measures would already be in place for the US and the UK, however these measures appeared not to have been implemented effectively. In contrast,

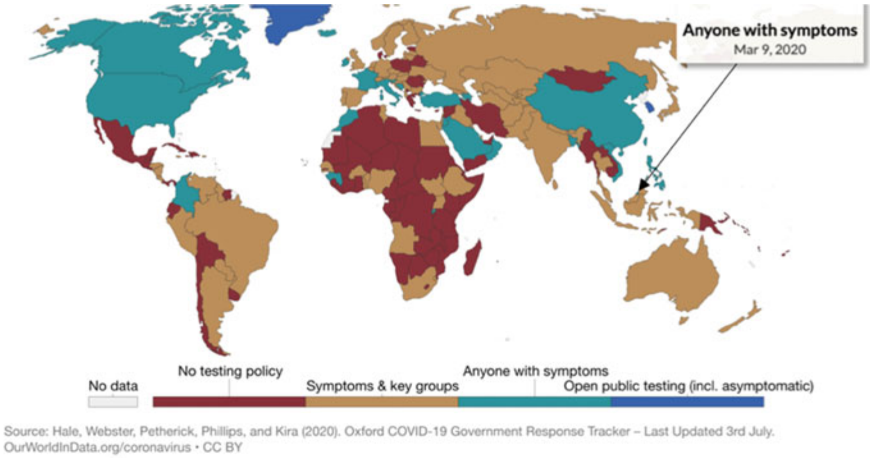

Fig. 8.8 COVID-19 Testing Policies as on March 9, 2020

credit should be given to China (as the originating hub of the pandemic) who had implemented testing policies to test citizens based on indication of flu-like symptoms and those who were in close contact with infected cases. Unfortunately, China was relatively slower in implementing testing policy code to "anyone with symptoms" on February 16, 2020 but only increased their policy to an "open public testing" policy on March 31, 2020. In the case of the United States, the first COVID-19 case was recorded on January 13, 2020 but their stringent testing policy was only implemented much later from February 28, 2020 (see also Fig. 8.8 for Testing Policies around the world).

8.3.7 Closure of Schools and Academic Institutes

Children are highly vulnerable to the potential of virus infections when studying in a dense student community. As such, most governments in respective countries have announced a significant policy to close schools and universities and restricted student and teacher gatherings to reduce further risk and exposure. To minimize disruption in the continuity of education, the ministries of education in respective countries have announced alternative teaching methods that focused on mainly online teaching.

As on March 11, 2020, the COVID-19 pandemic had spread to approximately 120 countries worldwide. However, only 38 of these affected countries had implemented policies to close the schools and academic institutes. As shown in Fig. 8.9, Brunei was one of only five countries (Brunei, Albania, Bhutan, Iraq and Pakistan) who had acted quickly in implementing school closures within a period of 1–2 days of confirmed the first case within their respective countries. The median

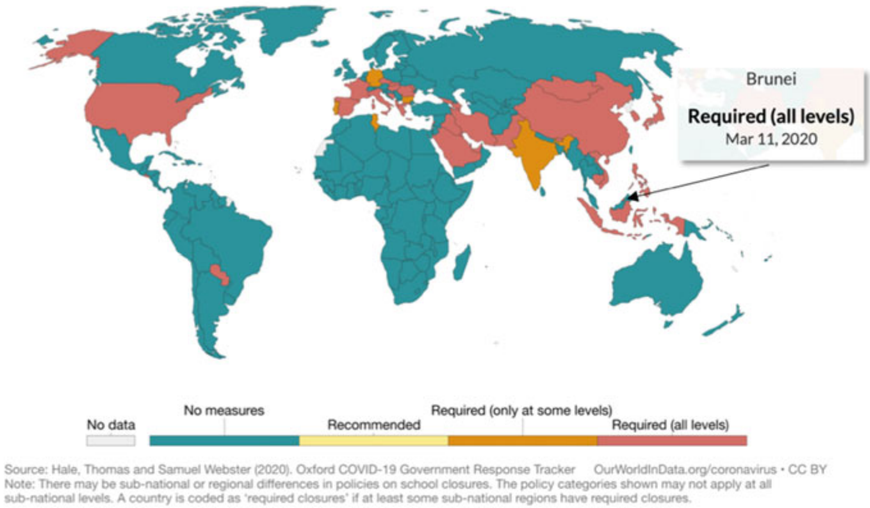

Fig. 8.9 School closures during the COVID-19 pandemic as on March 11, 2020

average time in implementing school closures for all 38 countries with similar policies was found to be 13.6 days from confirmation of the first case. While most countries implemented school closures only after the appearance of the first case, 2 countries, El Salvador and Mongolia had proactively implemented school closures in the country before the appearance of the first case.

Among the Southeast Asia countries, Brunei was the 8th out of the 10 ASEAN countries to be affected with the COVID-19 outbreak as on March 9, 2020 (Li-Lian 2020). Among the ten countries of Southeast Asia, the median average time to implement school closures was 19.6 days. Brunei was thus the fastest country among Southeast Asia countries to implement school closures within two days after the first infected case was reported.

8.3.8 Cancellation of Public Events and Restriction of Public Gatherings

China was the first country in the world to implement a policy on the cancellation of public events during the COVID-19 pandemic, by South Korea, the Philippines and Taiwan. Brunei had implemented a cancellation of public events across the country on March 13, 2020, within four days of the first confirmed case (see Fig. 8.10). By this time, many countries have already implemented some form of cancellation of public events in their respective countries. In comparison with other countries, Brunei was among the top five fastest countries in the world in carrying out this

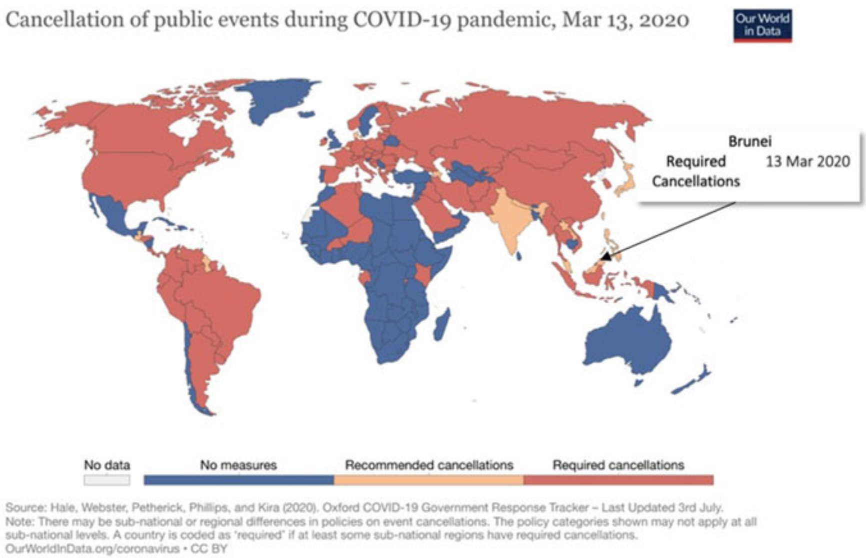

Fig. 8.10 Cancellation of public events during the COVID-19 pandemic as on March 13, 2020

action. It was also the third fastest country in Southeast Asia after Myanmar and Indonesia to cancel public events within a period of four days after the first confirmed case. The median average time taken after the first confirmed case to close public gatherings in Southeast Asia countries was 15.1 days.

Due to the potential spread of the virus during a public gathering, governments imposed a restriction on public gatherings to reduce and control widespread exposure of the pandemic. A global policy on the restriction on public gatherings is categorized as between Code 1 to 4 depending on the size of gatherings allowed (see Fig. 8.11) and provides a limit, with most countries still allowing small family or social gatherings. The categories are described as Code 1 (Public gatherings with more than 1,000 people), Code 2 (Public gatherings between 100 and 1,000 people), Code 3 (Public gatherings between 10 and 100 people) and Code 4 (Public gatherings with less than 10 people).

As on March 13, 2020, the COVID-19 outbreak had spread to 142 countries, of which only 49 (34.5%) countries had imposed different restrictions on public gatherings from 'no measures' in terms of restrictions or cancellation of public events, to 'recommended cancellation' and the last stage progressing into 'required cancellations' of public events (see Fig. 8.10). In the case of Brunei, within four days of the first confirmed case, a notice of restrictions on public gatherings was issued. The restriction on public gatherings in Brunei was categorized as Code 3 and was specifically limited to less than 30 people that were allowed in a closed premise at any given time. Brunei is also one out of thirteen countries in the world that imposed a restriction of Code 3 (10 to 100 people) on 13 March 2020, while seven countries, including China, had imposed a restriction of Code 4 (less than 10

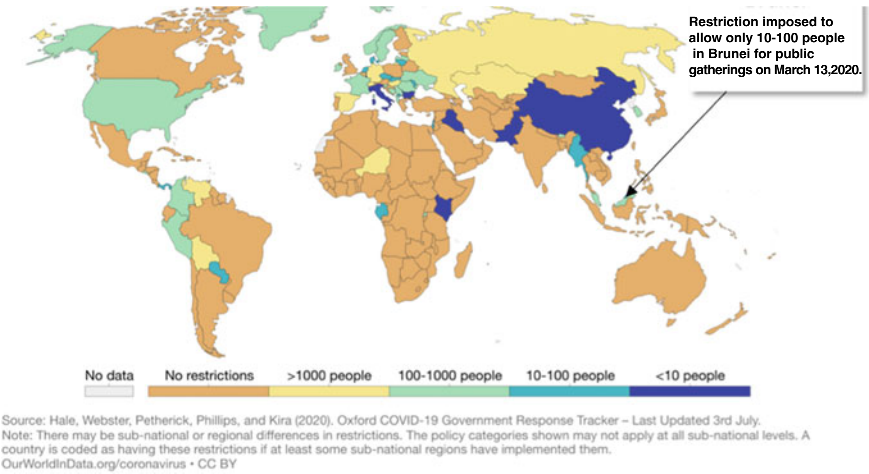

Fig. 8.11 Restrictions on public gatherings in the COVID-19 pandemic as of March 13, 2020

people), due to the severity of high infection rates. In comparison with Southeast Asia countries, only 3 out of 10 ASEAN countries had imposed gathering restrictions in their respective countries. Brunei was the 2nd fastest country after Myanmar in ASEAN to introduce restrictions within four days of after the first confirmed case (Li-Lian 2020). In relation to this, the median average time of various countries that were affected and imposed restrictions on public gatherings was around 13.7 days from the first confirmed case.

8.3.9 Review of Resilience Measures Adapted by Various Countries in Comparison to Brunei

8.3.9.1 Human Development Index Indicator Showing The Preparedness Towards the Control of the Pandemic Among Nations

The Human Development Index (HDI) is a statistic developed by the United Nations that measures a country’s economic and social development. HDI is measured in the range of 0 and 1 and provides a global comparison among developed/developing countries around the world. For the purpose of comparison in this paper, the HDI measurement can be used to identify whether a more developed country has a stronger advantage in suppressing the COVID-19 outbreak, when compared to a less developed one. A country with a higher HDI is presumably better equipped in terms of more experienced government, advanced health care systems, state-of-art infrastructure system, educated society, and most likely to possess technological advantages.

8.3.9.2 Countries Highly Cited for Better Control of This Pandemic

Apart from regular updates from WHO, each country worldwide have developed their respective preventive and precautionary measures to limit the spread of the COVID-19 outbreak. The media has reported that four countries, namely South Korea, Taiwan, Singapore and New Zealand, have been highly cited worldwide for their outstanding control of the COVID-19 outbreak (Shim 2020; Cousins 2020) and for flattening the COVID-19 outbreak curve. In comparison, Brunei, despite having successfully flattened the curve in the past 175 days, it is yet to receive recognition for its efforts and good governance policies during the pandemic.

To review the spread and control at the onset of the outbreak, the COVID-19 cases among the 4 notable nations are tabulated in Table 8.2. As shown in the table, South Korea (27 cases), Taiwan (48 cases) and New Zealand (39) showed lesser cases than Brunei (127 cases) in the first 3 weeks of the pandemic, while Singapore recorded more cases at 187 cases (Pung 2020). However, as of 6 July 2020, Singapore (44,664 cases) had shown the largest growth in cases in the country, followed by South Korea (13,091), New Zealand (1,183) and Taiwan (449). Despite these factors, Brunei has managed to completely flatten the curve with no new local cases for the past three consecutive months (as of October 28, 2020) with the exceptions of imported cases from returning travellers who came back to the to the country from overseas.

As of July 6, 2020, among the five countries listed in Table 8.2, South Korea can be viewed as the most performing in terms of reduced infection rates of cases per capita at 0.002%, followed by New Zealand at 0.024%, South Korea at 0.026%, Brunei at 0.032% and Singapore as the worst performing at 0.76%. In comparing New Zealand with Singapore, both countries with similar population and HDI, it is noted that Singapore had four times more cases than New Zealand by the Week 3 period.

Table 8.2 Comparison of COVID-19 Cases with notable countries that have flattened the curve

Country	3 week period from 1st case in country (2020)	No. of cases at week 3	No. of cases as of 6 July 2020	Population	Cases Per capita (%)	Global rank (Out of 215)	HDI
Brunei	**9 Mar–30 Mar**	**127**	**141**	**437,550**	0.032	**175**	**0.854**
South Korea	20 Jan–10 Feb	27	13,091	51,270,128	0.026	63	0.906
Taiwan	21 Jan–11 Feb	48	449	23,817,676	0.002	156	–
Singapore	23 Jan–13 Feb	187	44,664	5,851,166	0.763	38	0.935
New Zealand	28 Feb–20 Mar	39	1,183	5,002,100	0.024	122	0.921

8.3.9.3 Comparison Among the Nations Where Covid-19 Cases are Reported Within First 3 Weeks

In considering the precautionary actions taken by governments, it is useful to make a comparison on the number of cases per capita between Brunei with other countries that are listed in the top 10 most affected countries reported increased number of new cases per day (as compiled by (Worldometers, 2020)). The main criteria of comparison are based on the total number of cases within the first three weeks, after the first case has been confirmed in the respective countries. As shown in Table 8.3, the four countries are ranked as the highest increase in number of infected cases after only 3 weeks, namely the United States, India, Russia and the United Kingdom.

It can be found that the total number of cases for the 5 countries listed in Table 8.3 (apart from Brunei) has ranged from as low as 2 to 127 cases within the 3-week period (beginning January to March). India has the lowest cases per capita at 0.05%, with United States as the highest cases per capita at 0.87%. Both Russia and United Kingdom has similar cases per capita of less than 0.5%. During the same period, the total number of COVID-19 cases in Brunei, however, is significantly high at 127 cases on 30 March 2020 but the cases per capita is about 0.03%. As of July 6, 2020, there seems to be an influx in the number of infected cases among the 5 countries listed in Table 8.3, despite having only relatively small number of cases within that period. The infected cases have grown in these countries in three weeks. In contrast, the total number of cases in Brunei peaked at 141 cases and has not recorded any new local cases since May 7, 2020.

Brunei has a relatively small population and experienced an increase in infected cases that shot up from 0 to 127 cases within the first 3 weeks of the pandemic. It is expected that infected cases of COVID-19 will increase drastically due to people living in a geographically small location of a total area of 2,226 square miles and are likely to infect each other through close encounters, if no precautionary and strict measures were taken. Yet, after the first 3 weeks has passed, the growth of

Table 8.3 Comparison of COVID-19 confirmed cases among chosen countries as of three weeks from identification of first case

Country	3 week period from 1st case in country (2020)	No. of cases at week 3	No. of cases as of 6 July 2020	Population	Cases per capita (%)	Global rank (Out of 215)	HDI
Brunei	**9 Mar–30 Mar**	**127**	**141**	**437,550**	0.032	**175**	**0.854**
United States	13 Jan–3 Feb	11	2,890,000	331,039,330	0.873	1	0.920
India	30 Jan–20 Feb	3	720,346	1,380,233,788	0.052	3	0.647
Russia	31 Jan–21 Feb	2	687,862	145,935,812	0.471	4	0.824
United Kingdom	31 Jan–21 Feb	9	285,678	67,892,858	0.421	8	0.920

local COVID-19 cases in Brunei has remained low. The best possible explanation to explain the slowing down of the growth is that the Brunei government had taken various vigorous preventive measures and efficient contract tracing and strict quarantine measures.

Brunei, like many other countries has also been affected with the outbreak but had the fortune of learning from other countries, with adequate time to prepare in handling the outbreak. This has significantly benefited many nations, including Brunei, which had infected cases, which occurred at a later stage. Preventive measures taken by the Brunei government (see Table 8.1) to combat the spread of COVID-19 has been successful in flattening of the curve within a very short period of time, since the reported local case on May 6, 2020.

8.3.9.4 Spread of COVID-19 Outbreak in Other Nations Where the First Case was Reported on Same Day as Brunei

To further compare the growth of COVID cases in other countries with Brunei where the first case was recorded on the same day (March 9, 2020), this will negate any contention that additional time provided Brunei with significant advantage in lowering the number of infected cases. As shown in Table 8.4, on March 9, 2020, the first confirmed COVID-19 case was recorded in several other countries and territories in the world: Brunei, Cyprus, Guernsey and Panama.

From the above table (Table 8.4), it can be seen that after reporting the first case on March 9, 2020, within the first 3 weeks, the number of cases per capita differed in each country. Panama (1,075 cases) had a high number of cases with 0.91% cases per capita, followed by Guersney (39 cases) with 0.4% cases per capita, Cyprus (230 cases) with 0.08% per capita, and Brunei (127 cases) with 0.03% cases per capita. Brunei has achieved the lowest cases per capita among the 4 countries listed in Table 8.4 during the same observation period from March 9–20, 2020. In contrast, it is significant that that Guernsey has a population that is nearly 7 times smaller than Brunei but the cases per capita is still considerably high for a small population.

Table 8.4 Comparison of COVID-19 cases in countries infected on the same date as Brunei

Country	3 week period from 1st case in country (2020)	No of cases at week 3	Cases as of 6 July 2020	Population	Cases per capita (%)	Global rank (Out of 215)	HDI
Brunei	**9 Mar–30 Mar**	**127**	**141**	**437,550**	0.032	**175**	**0.854**
Panama	9 Mar–30 Mar	1,075	39,334	4,315,710	0.911	41	0.795
Cyprus	9 Mar–30 Mar	230	1,004	1,207,519	0.083	135	0.873
Guernsey	9 Mar–30 Mar	39	252	63,026	0.400	–	

8.3.9.5 Comparison of Spread of COVID-19 Outbreak in Nations Per Capita Cases

It can be argued that the total population of a country correlates to the number of infected cases, per capita. In order to provide a fair comparison, the number of cases per capita is calculated and displayed with countries of cases with similar small populations. In Table 8.5, there are 8 countries and territories listed with similar or less population than Brunei. The median average population for all the nine (including Brunei) is 333,720 with the lowest population at 33,932 (San Marino) and the highest population at 626,117 (Luxembourg). As such, Brunei with a population of 437,550 has a larger population than the median average. The infection date for these countries/territories range as early as February 27, 2020 (11 days before Brunei) and as late as 15 March 2020 (4 days after Brunei). At the same time, in terms of HDI, the four countries were of higher HDI than Brunei, two countries had lower HDI and the HDI of two countries were not listed. The infected cases per capita are also compared in the following table.

As seen in Table 8.5, among all the nine countries, 5 of the 9 countries reported lower cases than Brunei in the first 3 weeks period after the first confirmed case. These include Suriname (5 cases) with 0.1% cases per capita, Cayman Island (22 cases) with 0.3% cases per capita, Bahamas (29 cases) with 0.03% cases per capita, San Marino (109 cases) with 2.1% cases per capita, Andorra (113 cases) with 0.15% cases per capita. Among the countries listed in Table 8.5, Luxembourg recorded the highest number of cases (484 cases) with 0.72% cases per capita. The lower cases per capita reflect that two countries/territories, Bahamas and Brunei have lowered infection rates (of less than 0.05%) despite achieving infected cases above 100 as on July 6, 2020. With the exception of the Bahamas, Brunei had

Table 8.5 Comparison of COVID-19 Cases in various countries/territories with similar population to Brunei on 3-week period from 1st case

Country	3 week period from 1st case in country (2020)	No. of cases at week 3	Cases as of 6 July 2020	Population	Cases per capita (%)	Global rank (out of 215)	HD
Brunei	**9 Mar–30 Mar**	**127**	**141**	**437,550**	0.032	**175**	**0.854**
San Marino	27 Feb–19 Mar	109	713	33,932	2.101	148	–
Iceland	28 Feb–20 Mar	330	1,863	341,284	0.546	113	0.938
Luxembourg	29 Feb–21 Mar	484	4,522	626,117	0.722	92	0.909
Andorra	2 Mar–23 Mar	113	855	77,268	1.107	142	0.857
Malta	7 Mar–28 Mar	149	672	441,567	0.152	150	0.885
Cayman Islands	12 Mar–2 Apr	22	201	65,734	0.306	169	–
Suriname	13 Mar–3 Apr	10	594	586,723	0.101	151	0.724
Bahamas	15 Mar–5 Apr	28	104	393,308	0.026	180	0.805

outperformed among all other nations in terms of the total number of cases. Remarkably, four of these seven countries were also found to have a higher HDI than Brunei. However, it is also notable to point out that Bahamas continues to report daily cases since March 16, 2020 and new cases has spiked to 2330 cases since October 28, 2020. In comparison, the last local case recorded in Brunei was on May 6, 2020, bringing the total 141 cases. As of October 26, 2020, Brunei has not recorded any new local cases in nearly over the past 6 months with 7 imported cases, and 1 current active case.

As previously seen from Table 8.3, that both the United States and the United Kingdom shared a high HDI of 0.92. Despite the United States and the United Kingdom being as categorized as under *very high* human development, the assumptions that these countries with very high HDI with better health care settings could not successfully suppress the spread of the outbreak. It should also be emphasized that the Global Health Security Index (GHSI, 2019) has ranked the United States and the United Kingdom as 1st and 2nd respectively among the 195 countries in the world, which are as best prepared to deal with a pandemic. Interestingly, Brunei is ranked at 128 on the GHSI but has performed significantly well to suppress the growth of the outbreak in the country. Even though the number of confirmed cases in Brunei was very high within the first 3 weeks, Brunei was still able to drastically flatten the curve afterwards. In contrast, countries that currently topped the reported highest coronavirus cases, as of October 28, 2020 are United States (Ranked 1), India (Ranked 2), Brazil (Ranked 3), Russia (Ranked 4), France (Ranked 5), Spain (Ranked 6), Argentina (Ranked 7), Columbia (Ranked 8), United Kingdom (Ranked 9) and Mexico (Ranked 10), in which these 10 countries had recorded far lesser cases within the first 3 weeks as compared to Brunei. This reflection emphasizes on the importance of implementing strong preventive and precautionary measures and to plan quickly and efficiently in order to handle and suppress such an outbreak.

8.3.9.6 Resilience Measures Among the Nations Where the First Case was Reported a Week Before Brunei's

Brunei was compared with countries that were affected by the COVID-19 outbreak in 1-week period (March 2–8, 2020) before the first COVID-19 case appeared (on March 9, 2020) in Brunei (see Table 8.6). The purpose of the comparison is to evaluate how other countries (based on similar outbreak timelines) has fared in handling the COVID-19 outbreak and resilience measures taken to contain the spread. As such, each respective country had developed its own policies that range from international travel restrictions, school closures, lockdowns and other social distancing measures, among others (Thunström 2020).

It can be seen that the Maldives (16 cases) and Cameroon (91 cases) have better performed, resulting in lower cases compared to Brunei (141 cases) within the first 3 weeks. However, Poland was the worst performing of all countries in Table 8.6, with total COVID-19 cases reaching as high as 1,051 cases within the same period. As on July 6, 2020, after reviewing the growth of cases in these countries, the

Table 8.6 Comparison of COVID-19 Cases in Countries infected within the 7 days before Brunei

Country	3 week period from 1st case in country (2020)	No. of cases at week 3	No. of cases as of 6 July 2020	Population	Cases per capita (%)	Global rank (Out of 215)	HDI
Brunei	**9 Mar–30 Mar**	**127**	**141**	**437,550**	0.032	**175**	**0.854**
Saudi Arabia	2 Mar–23 Mar	562	213,716	34,821,448	0.614	13	0.857
Indonesia	2 Mar–23 Mar	579	64,598	273,571,432	0.024	26	0.707
Poland	4 Mar–25 Mar	1051	36,155	37,845,686	0.096	43	0.872
Cameroon	6 Mar–27 Mar	91	12,592	26,551,860	0.047	62	0.563
Peru	6 Mar–27 Mar	635	305,703	32,978,661	0.927	5	0.759
Maldives	7 Mar–28 Mar	16	2,468	540,667	0.456	105	0.719

effectiveness of the implementation of preventive measures and other factors are more apparent. The cases per capita among the 7 countries listed in Table 8.6, however, showed that three countries, including Indonesia (Cases Per Capita 0.02%), Brunei (Cases Per Capita 0.03%) and Cameroon (Cases Per Capita 0.05%) are much lower, indicating significant containment of the spread of the virus in these respective nations, thus performing much better than the other 7 countries, within the same 3 week period, March 2–30, 2020.

The most significant growth in cases, however, was seen in Peru. As of October 28, 2020. Peru which only 635 cases in the first 3 week period has now ranked as the 11th highest number of COVID-19 cases in the world with 897,594 cases. Similarly, Indonesia with 579 cases has escalated to 404,760 cases (ranked 19th), Saudi Arabia with 562 cases and has escalated to 346,482 cases (ranked 24th), Poland with 1051 cases, and has escalated to 319,205 cases (ranked 27th). Two countries, Cameroon (ranked 91st) with 91 cases, has now escalated to 21,793 cases, while Maldives (ranked 107th) with 16 cases, has escalated to 11,616 cases.

Among the 7 countries, Brunei has experienced an increase of 11% from 127 to 141 cases and ranked as 194th among the total of 218 listed countries/territories as shown in the Report on COVID-19 Coronavirus Pandemic (WorldOMeter). The argument could also be stretched to explain that other external factors such as the size of the population and time in preparation days for the pandemic as discussed in this paper may have some advantageous to a small nation, such as Brunei. However, in arguing the defense of population size, a comparison could be made between two cases, Brunei and Maldives (both of relatively similar population size). The cases per capita differed with Brunei achieving at less than 0.05% and Maldives at 0.45%. This indicates that population size is not likely to be determining factor in the case of the spread of the outbreak. In addition, both Brunei and Maldives have population of approximately half a million. It can be argued that Maldives should have some advantage over Brunei, as Maldives had 16 cases compared to the 141 cases in Brunei over the first 3-week period of the outbreak. Yet, today, infected cases in Maldives have drastically increased from 16 to 11,616 cases, while the total number of cases in Brunei has only increased from 127 to 141 cases.

Overall, in comparing the figures in Tables 8.3, 8.4, 8.5 and 8.6, it can be noted that Brunei has outperformed and kept the infection rates at very low levels among all the countries that have been discussed in this paper.

8.3.9.7 Overall Perspective of an Outbreak in Brunei Compared to the Global Nations

WorldOmeter (Worldometers, 2020) provides daily updates on COVID-19 related statistics, including total and daily new cases that represent 218 countries and territories. As on October 28, 2020, Brunei is one of the few countries in the world that have not seen any new local infection or experience any drastic increase in cases for over three months to the point that Brunei has successfully *flattening the curve* (Hamid 2020). According to Hamid (2020), it is unlikely for local outbreaks to occur in the country, unless the government was lax with immigration that allow imported cases into the country. As of October 28, 2020, with the return of citizens and local travellers from overseas into the country, recently that Brunei has received 7 new imported cases from August 7, 2020, with 6 cases that have fully recovered, and 1 active case.

The information detailed in this paper has thus compared Brunei with other countries and outlined the massive preparations and stringent responses from the Brunei Government to combat the outbreak, including the setting up and operation of the National Health Centre in less than 1 week. Brunei has also imposed strict precautionary measures by imposing travel ban and implemented immediate closure of schools and institution throughout the state. Access to public places including eateries, government departments, and other social venues have been carefully monitored and were restricted, whilst various de-escalation stages were put into action. In addition, there is constant surveillance, with strict rules and limitations for the general public when entering crowded places, such as shopping malls, and government venues and other public places. This is complemented with close monitoring of the public via the Health Application, BruHealth and PremiseScan and through contact tracing. Infected cases have also been carefully managed at the National Isolation Centre. There were also strict quarantine measures for returning travellers into Brunei, with strict travel bans and movement for the people entering and leaving Brunei (see also Table 8.1). Among others, the precautionary measures included sanitization, wearing facemasks, and compulsory daily monitoring and temperate checks for each person through controlled entry points throughout Brunei. There was also constant sharing of information about social distancing, dissemination of daily updates on the coronavirus shared on Telegram, which is the official government platform for sharing information about COVID-19. All these factors, combined with the strict adherence to government guidelines and co-operation of the people have led to successful flattening of the curve in Brunei.

Overall, in comparing figures from Tables 8.3, 8.4, 8.5 and 8.6, it can be argued that Brunei has outperformed and kept its infection rates at very low levels among all the countries that have been discussed in this paper.

8.3.9.8 Salient Resilience Features of Brunei Government and Mitigation, Measures to Suppress the Outbreak

Brunei has performed extremely well in terms of being successful in suppressing the outbreak and *flattening the curve*. The success accomplished by Brunei is the result of the proactive preventive measures taken by the Brunei government as early as January 1, 2020 despite that the first COVID-19 case in Brunei has not been recorded on March 9, 2020. Among the credit and preventive measures taken by the Brunei government showed that Brunei is:

- 1 of 4 countries in the world to establish contact tracing measures as early as January 1, 2020.
- 1 of 2 countries to implement a coordinated information campaign by the national government on January 6, 2020.
- 1 of 7 countries to have implemented a ban on the high-risk region for international travel control measures by January 22, 2020.
- 1 of 5 countries from 120 affected countries to implement school closures fast within 1 to 2 days and was also the fastest country in Southeast Asia to do so.
- Among the fastest in the world to implement testing policy (done on the same day when the first COVID-19 case appeared in the country on March 9, 2020).
- Among the fastest countries in the world to implement cancellation of public events within 4 days and is the 3rd fastest country to implement this preventive measure in Southeast Asia.
- 1 of 20 from 142 countries to implement restrictions on the public gatherings by March 13, 2020 and the 2nd fastest to implement this measure in countries from Southeast Asia.

8.4 Conclusions

As early as January 2020, the Brunei government had implemented proactive precautionary measures to prevent and suppress the COVID-19 outbreak before its appearance in March 2020 in the country. Since the spread of the first case in Brunei, the Brunei government has initiated numerous significant efforts, and conducted various awareness campaigns to educate the public in order to mitigate the spread of the outbreak. Various resilience measures and policies that were taken by the Brunei government and compared with other nations were extensively reviewed and highlighted in this research article. It can be concluded that the strong actions undertaken by the Brunei government, and success achieved in Brunei was due to a combination of early government action, speedy implementation of policies and initiatives as well as the public cooperation. This has resulted in the complete flattening of the curve and maintains zero new cases for over 175 days as on October 28, 2020. This detailed study and notable polices can provide as a framework for other nations to contain future pandemics to achieve sustainable society.

Electronic Supplementary Materials

1. *Data collected from press release released by the Brunei government*
2. *Review of COVID-19 Government Response Stringency Index among the world*

Conflict of Interest
No conflict of interest.

Contribution
MZSAH (Data collection, Data compiling & editing); RRK (Conceptualization, Mentoring and editing).

Funding: No funding received.

References

Baker MG, Wilson N, Anglemyer A (2020) Successful elimination of covid-19 transmission in New Zealand. N Engl J Med 383(8):e56

Cousins S (2020) New Zealand eliminates COVID-19. The Lancet 395(10235):1474

Eliza B, Dylan S, Christina A (2020) Chart: The US doesn't just need to flatten the curve. It needs to “raise the line‶, [Apr 7, 2020 July 11, 2020]. Available from https://www.vox.com/2020/4/7/21201260/coronavirus-usa-chart-mask-shortage-ventilators-flatten-the-curve

Fouda A et al. (2020) *The COVID-19 pandemic in Greece, Iceland, New Zealand, and Singapore: Health Policies and Lessons Learned.* Health Policy

Hamid MZSA (2020) An analysis of the success of suppressing COVID-19 cases in Brunei Darussalam. Int J Adv Res 8(6):718–725

Li-Lian SS (2020) ASEAN’s Covid-19 Pandemic Response: Practical Next Steps

Pung R et al. (2020) *Investigation of three clusters of COVID-19 in Singapore: implications for surveillance and response measures.* The Lancet

Roser M et al. (2020) Coronavirus pandemic (COVID-19), [11 July 2020]. Available from https://ourworldindata.org/policy-responses-covid

Shim E et al. (2020) Transmission potential and severity of COVID-19 in South Korea. International Journal of Infectious Diseases.

Thunström L et al. (2020) The benefits and costs of using social distancing to flatten the curve for COVID-19. J Benefit-Cost Anal, pp. 1–27.

WHO (2020) World Health Organization-Modes of transmission of virus causing COVID-19: implications for IPC precaution recommendations: scientific brief. *27 March 2020*. World Health Organization

Wong J et al (2020) Responding to COVID-19 in Brunei Darussalam: lessons for small countries. J Glob Health 10(1):010363–010363

Wong J et al. (2020) Epidemiological investigation of the first 135 COVID-19 cases in Brunei: implications for surveillance, control, and travel restrictions. Am J Trop Med, p. tpmd200771

Wong JE, Leo YS, Tan CC (2020) COVID-19 in Singapore—current experience: critical global issues that require attention and action. J Am Med Assoc 323(13):1243–1244

Worldometers (2020) *Covid-19 Coronavirus Pandemic* [2020, Jul 20]. Available from https://www.worldometers.info/coronavirus/

Wu Y-C, Chen C-S, Chan Y-J (2020) The outbreak of COVID-19: an overview. J Chin Med Assoc 83(3):217

Chapter 9
Precarious Aging: COVID-19 Risk, Resilience and Response

Andrew V. Wister

Abstract Coronavirus disease (COVID-19) is a highly contagious pathogen that has shown to result in high rates of morbidity and mortality. In early 2020, the COVID-19 global crisis appeared in numerous countries, spreading rapidly with multiple waves of infection. This has resulted in unprecedented health, social and economic challenges in terms of public health, health and continuing care systems, economies, communities, and families. We have conceptualized COVID-19 as a 'gero-pandemic,' defined as a disease that has spread globally with heightened significance and deleterious consequences for older people. This chapter examines the structural, system-level contexts of COVID-19, and individual-level risks, experiences and responses. We frame this chapter using a resilience model of aging, which provides a multi-level conceptual apparatus for understanding how societies and individuals overcome the adversities created by the COVID-19 gero-pandemic by identifying systemic weaknesses/problems, areas of strength and resilience, and evidence for successful mitigation and innovative responses. We are led to several core recommendations for public health and health promotion as societies attempt to adapt and respond to the COVID-19 crisis.

Keywords "Gero-pandemic" · Gerontology and COVID-19 · Resilience model of aging · Aging resilience

9.1 Introduction

The COVID-19 'Gero-pandemic' Coronavirus disease (COVID-19) is a recently discovered pathogen that is highly contagious, and which has proven to result in high rates of morbidity and mortality (Liu et al. 2020; Renu et al. 2020). It has

A. V. Wister (✉)
Director and Professor, Gerontology Research Centre and Department of Gerontology, Simon Fraser University, 2800-515 Hastings Street Vancouver, Burnaby, BC V6B 5K3, Canada
e-mail: wister@sfu.ca

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_9

proven to be difficult to control, given that it has a wide spectrum of symptoms including asymptomatic forms. In early 2020, the COVID-19 global crisis appeared in numerous countries, spreading rapidly with multiple waves of infection, and resulted in unprecedented social change and challenges in terms of public health, health and continuing care systems, economies, communities, and families. Although there have been numerous other pandemics in recent history (e.g., HIV/AIDS, H1N1, SARS, MERS, etc.), COVID-19 has developed into one of the most serious pandemics for almost a century, since the occurrence of the Spanish flu. Furthermore, COVID-19 has been conceptualized as a 'gero-pandemic,' defined as a disease that has spread globally with heightened significance and deleterious consequences for older people (Wister and Speechley 2020). Given these disease parameters, this chapter seeks to examine the structural, system-level contexts of COVID-19, and individual-level risks, experiences and responses. A key question is: what are the system and individual-level risk and response factors that mitigate positive adaptation to this gero-pandemic? This chapter offers recommendations for the examination of the COVID-19 crisis with a focus on North America, and public health and health promotion responses to the inherent problems. We frame this chapter using a resilience model of aging, which provides a multi-level conceptual apparatus for understanding how societies and individuals overcome the adversities created by the COVID-19 gero-pandemic by identifying systemic weaknesses/problems, areas of strength and resilience, and evidence for successful mitigation and innovative responses.

9.2 COVID-19: A 'Gero-Pandemic'

This chapter conceptualizes COVID-19 as a gero-pandemic, given that prevalence, morbidity and mortality risk is highest among the oldest cohorts in our populations (Blagosklonny 2020; Mitra et al. 2020; Shahid et al. 2020). Based on prevalence as of the third week of March 2021, COVID-19 cases surpassed 29.5 million in the US, and 28.5 million worldwide, and these are likely underestimates because of current testing limitations. The number of deaths will soon reach 550,000 in the US and is fast approaching the 3 million mark globally (Government of Canada 2020). Furthermore, examination of age differences in the hospitalization and death statistics, clearly demonstrates why this is a gero-pandemic. As shown in Table 9.1, as of August 2020, persons aged 65–74, 75–84 and 85 + have a probability of hospitalization that is 5, 8 and 13 times higher respectfully, compared to persons aged 18–24 (selected comparison group) (CDC 2020). Even more striking, persons aged 65–74, 75–84 and 85 + have a probability of death that is 90, 220, 630 times higher respectfully, compared to persons aged 18–24 (CDC 2020). From a generational perspective, the majority of North American COVID-19 cases comprise the baby boomers—persons born between 1946 and 1965 (approximately 55–74 years of age today)—plus the smaller generation of persons born during the Great Depression who are now 75 years old and older (Cohen and Tavares 2020).

Table 9.1 COVID-19 Hospitalization and death by age

	0–4 years	5–17 years	18–29 years	30–39 years	40–49 years	50–64 years	65–74 years	75–84 years	85 + years
Hospitalization[a]	4 × lower	9 × lower	Comparison group	2 × higher	3 × higher	4 × higher	5 × higher	8 × higher	13 × higher
Death[b]	9 × lower	16 × lower	Comparison group	4 × higher	10 × higher	30 × higher	90 × higher	220 × higher	630 × higher

[a]Data source: COVID-NET (https://www.cdc.gov/coronavirus/2019-ncov/covid-data/covidview/index.html, accessed 8/31/20). Numbers are unadjusted rate ratios

[b]Data source: NCHS Provisional Death Counts (https://www.cdc.gov/nchs/nvss/vsrr/COVID19/index.htm, accessed 08/31/20). Numbers are unadjusted rate ratios

Thus, an aging lens is useful in order to examine age groups/cohorts and generational differences in pandemic experiences from a public health system perspective (Shahid et al. 2020; Wister and Speechley 2020).

However, many gaps and inaccuracies of detailed public health and epidemiologic data limit the ability to maximize our ability to monitor and respond to the pandemic. Some contributing factors entail: (1) a significant proportion of individuals are asymptomatic and therefore do not typically get tested; (2) there are testing inaccuracies (false positives and false negatives); (3) testing has not kept pace with demand; (4) individuals do not fully understand symptomology and differentially perceive its seriousness; (5) there are state, regional, and local differences in these testing patterns; and (6) there is systematic disinformation within the global community In addition, there are variations in how COVID-19 cause of death is determined, for example, some older adults who died in long-term care (LTC) due to multiple causes may not have been counted as COVID-19 deaths. All of these issues likely result in underestimates of COVID-19 cases and deaths. The disease-specific complexities associated with COVID-19, coupled with problems and challenges embedded in our public health, health care, and continuing care systems, creates enormous challenges in coping with the COVID-19 pandemic.

While age has become a major focal point in the pandemic due to higher prevalence, and moreover, adverse outcomes (Morrow-Howell et al. 2020; Shahid et al. 2020), it is also important to gain an understanding of other important social structures and contexts that intersect to shape disease risk inequality. However, detailed data showing COVID-19 cases, hospitalizations and death by age, race/ethnicity, and income categories are limited to date. More specific data, granulation, and contextual information are needed on a full spectrum of characteristics associated with inequality and social deprivation that interrelate with not only basic demographic categories, but also work status, gender, sexual orientation, neighbourhood/regional factors, and other social determinants of health. In addition, we know little about the role of immunosenescence (the natural deterioration of the immune system with advanced age) in affecting the negative outcomes (severity of illness, hospitalization, long-term damage, and death) among older adults (Blagosklonny 2020). Finally, while some data are available on pre-exiting conditions that place older people at heightened risk of COVID-19 and poor health outcomes, such as depression (Alonzi et al. 2020), cardiovascular disease, cancer, diabetes, and chronic obstructive pulmonary disease and other respiratory conditions (Mauvais-Jarvis, 2020), the longer-term health consequences for those who recover from the disease, and the broader societal implications for population aging and health remain largely unknown (Morrow-Howell et al. 2020; Shahid et al. 2020).

9.3 A Risk, Resilience and Response Perspective

A useful framework for understanding the COVID-19 pandemic risk and response from a gerontological perspective is the application of a resilience model of aging, which has received increasing attention in the gerontological literature (Windle 2012; Wister in press). It incorporates three interlocking, well-established models: (1) a complex systems model; (2) a socio-ecological model (Stokols 1992); and (3) a social determinants of health model (Rootman et al. 2012). A complex systems approach to resilience (e.g., disaster research) attempts to link and quantify the different individual and environmental-level spheres of influence observed within existing socio-ecological frameworks (Klasa et al. 2021a; Linkov and Kott 2019). Socio-ecological theory posits that individuals, social systems, and the environment are interrelated and interdependent, and emphasize how public health at the individual (micro) level requires consideration of interpersonal relationships (meso) and social policy and system-level organization (macro) (Stokols 1992). A social determinants of health perspective helps to understand the actual and perceived risk, seriousness, vulnerability and societal reactions to COVID-19 (Barber and Kim 2020). This requires consideration of age-related system-level risk, resilience and response coupled with their manifestation at the individual, family, community, municipal, state and federal level. Additionally, social determinants of health recognizes the import of other social and environmental contextual factors, such as poverty, societal perceptions of race, education, pandemics, and the physical environment can influence the health outcomes of individuals, families and communities (Klasa et al. 2021a). Together these models elucidate how adversity manifests itself for systems and individuals, but also the mitigation, positive adaptation and responses of people and society—what we might conceptualizes as community resilience to COVID-19.

While there are numerous definitions and types of resilience, we highlight two—a systems-based definition, and one drawing from social-psychological literature. When combined, these capture the unified approach taken in this chapter. The US Global Change Research Program (USGCRP) has defined disaster resilience as “a capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment” (USGCRP 2020). In addition, Ungar (2008:225) states that resilience is “both the capacity of individuals to *navigate* the psychological, social, cultural and physical resources that sustain their well-being, and their capacity individually and collectively to *negotiate* for these resources to be provided and experienced in culturally meaningful ways.” In this sense, a COVID-19 resilience approach identifies areas of risk and vulnerability, and the presence (or not) of strength-based responses at both the macro system and micro-individual levels. For instance, older adults living in LTCe (i.e., nursing homes, assisted living, congregate care, etc.) have extremely low individual resilience, which is typically not amenable to improvement given their frailty level (Andrew et al. 2020). Concurrently, the LTC systems have significant weaknesses and gaps in pandemic preparation and functioning, but which are mutable (Fisman et al. 2020). In this sense, a resilience model *balances* the negative effects of the disease and its deleterious effects on people and society with one that draws attention to positive adaptation so that we can forge more effective and efficient strength-based public health responses to the current and future pandemics (Wister and Speechley 2020). For example, while older community living Americans tended to report greater risk of dying from COVID-19, they held less negative emotions, better mental health and fewer depression and anxiety symptoms, than their younger counterparts (Bruine de Bruin 2020). A resilience approach therefore identifies key areas in which health care and public health systems have not performed optimally, thus directing reforms and adaptations to health care and public policy and programs. Both individual-level (e.g., physical distancing, mas wearing) and system-level (health care policy, local area mitigation policies) responses are needed to rebalance and reintegrate people and systems. This requires that we address those who have experienced the disease firsthand and those who experience the social (isolation, ageism), psychological (chronic stress, depression), and economic (loss of income, work disruption) outcomes of COVID-19 (Ong et al. 2006; Sells et al. 2009; Wister and Speechley 2020).

A resilience and aging model also provides a dynamic approach to understanding responses and adaptations to the COVID-19 crisis (Klasa et al. 2021b). A crucial phase of the resilience process is the underlying motivation and energy needed for accessing and activating resources embedded in the individual, family, community and system and broader socio-political environments (including governance systems) (Clark et al. 2011; Richardson 2002; Wister et al. 2016, 2020). Internal activation of resources is an expression of agency and self-efficacy, whereas external activation of resources includes tapping into system-level domains to mitigate risk and deleterious health, social and economic outcomes. Harnessing resources is integral to adaptive processes necessary to move older adults towards wellness, recovery, balance, and possibly personal and system-level development in the face of pandemic adversities, such as disease risk perception, social isolation, obtaining necessities, and underlying chronic stress (Bergman et al. 2020). Externally, there is a nexus of complex systems that comprise the macro-environment within which individual health is manifested. For example, the organization of the LTC system (public/private, ownership, size, density, visitation, protective gear for staff, and testing) has directly affected COVID-19 disease risk (Gardner et al. 2020; Klasa et al. 2021b).

Axioms of a COVID-19 Resilience and Aging Model

- Resilience is a protective, adaptive, restorative and/or coping response to the COVID-19 crisis.
- It can be useful in understanding the role of cycles of disruption and reintegration in rebalancing system and individual health and well-being, and the key resources that need to be available and harnessed to assist mitigation and bouncing back from pandemic adversity (Wister et al. 2016).

- Adversity due to COVID-19 ranges in type, severity, fluidity, and duration, both in terms of disease epidemiology and its impact on the lives of older people with or without the disease.
- The underlying mechanisms and processes of resilience are connected to the life course of individuals and are central to impacts on key outcomes.
- Similar to public health and health promotion models, resilience resources are embedded in the individual, family, community, system and broader socio-political environments.
- Accessibility and availability of individual and system-level resources that can be harnessed strengthen resilience.
- COVID-19 resilience is experienced at multiple levels—including physiological, psychological and institutional disruptions and responses to well-being, social manifestations, and those occurring at a community or system level.
- There are both generic components of COVID-19 resilience common across types of adversity, populations and time-periods, and specific ones related to unique dimensions or diversity of groups.

Adapted from Wister and Cosco (2021).

9.4 Risk, Vulnerability and Aging During a Pandemic

The COVID-19 pandemic has had a heightened negative impact on high-risk groups of older adults in terms of infection risk, morbidity (short and long-term), mortality, and its effects on activities of daily living, health behaviors, social engagement, and quality of life. Indeed, older adults are at greater risk of COVID-19, especially the most vulnerable groups, in particular those living in a long-term care (LTC) system (facility-based care for people with serious and/or complex health care needs) or any type of congregate living environment (e.g., retirement homes, assisted living, congregate care, and supportive living). Those living in the community are also at increased risk of contracting the disease and its deleterious outcomes, due to higher multimorbidity, especially the presence of pre-existing respiratory illnesses (Cohen and Taveres 2020; Xu et al. 2020). Furthermore, even though most older adults living in the community in private households are relatively healthy and active, the pandemic has produced greater levels of stress, social isolation and barriers to meeting day-to-day needs. Physical distancing and other forms of mitigation have exacerbated many of the social problems experienced by older individuals, covering a spectrum of health care, economic, physiological, social and psychological issues. The pathogenic components of COVID-19 have manifested themselves into numerous areas of life among older people including: obtaining food, supplies, medicines and medical care; physical activity; civic engagement; and the maintenance of social connections and physical touch (especially with family members and friends). The following subsections cover a selection of vulnerable groups of older people and examine public health and health promotion challenges as well as COVID-19 resilience responses.

9.5 Risk, Resilience and Response Among Selected Vulnerable Older Groups

Long-term Care (LTC), Congregate Living, and Community Care Systems

Older adults living in LTC (including congregate living environments, retirement homes, supportive housing, assisted living, etc.), are exposed to increased COVID-19 infection risk due to living in institutions designed as group quarters with short physical distances among residents, and group meals and activities (Béland and Marier 2020; Fisman et al. 2020; Gardner et al. 2020; McMichael et al. 2020; Shippee et al. 2020). Given that more women live in LTC and are housed in group quarters places them at increased risk, especially if members of a racial or minority group, who tend to have more severe and complex pre-existing conditions, and live in less resourced and staffed LTCs (Shippee et al. 2020). Infection risk is exacerbated when staff are required to re-use personal protective equipment because of shortages, staff work at more than one facility (often due to being poorly paid), and/or the design (size, structure, room allocation) of the facility. Undoubtedly, institutionalized older adults have a higher prevalence of disability, multimorbidity, frailty and/or cognitive impairment than community-living older people, factors associated with negative disease outcomes (Béland and Marier 2020; Fisman et al. 2020; Gardner et al. 2020; Laxton et al. 2020; McMichael et al. 2020).

Indeed, the COVID-19 pandemic has exposed many long-standing systemic problems and inadequacies in LTC and community care. Andrew et al. (2020:428–429) apply a socio-ecological approach to framing LTC COVID-19 risk factors. The authors contend that, at the individual level, residents are more likely to have pre-existing multimorbidities, high physical and cognitive frailty levels that mask early detection and magnify deleterious illness outcomes, including mortality. At the family level, physical isolation removes the patient from an informal support system that can help to detect the onset of the disease and provide a variety of supports (Hado and Feinberg 2020). At the institutional and facility level, health promotion programs designed to engage older adults in programs to enhance their health and well-being are deemed contributors to the spread of COVID-19, along with congregate meals, multiple person rooms, and small spaces (Andrew et al. 2020). The pandemic has also revealed in many countries problems of underfunding of the LTC system, staffing shortages, low paid staff who may not be able to take sick leave, training and remuneration, organizational and design-related deficiencies, or inadvertently spreading infection among facilities by working part-time at several facilities. At the community level, facilities located in COVID-19 hot spots are particularly at risk, especially in marginalized communities. On a contextual policy level there exist enormous differences in LTC policies across counties, states/provinces, health districts and regions, such as COVID-19 testing ability, personal protective equipment, maximum room size, staffing policies, staff training, and overall administration (Andrew et al. 2020).

For instance, approximately 7% of older Canadians (Employment and Social Development Canada 2019) lived in a highly institutionalized and bureaucratized LTC system that functions (both privately and publicly) outside of the Canada Health Act and the universal health care system. This has led to a fragmented system with varying standards across the country, and several provinces finding appalling conditions in some LTC homes (e.g. Ontario and Quebec) (Béland and Marier 2020). Simply, we have normalized the congregate housing of large numbers of physically and mentally challenged older adults in a single facility for economies of scale, sometimes with multiple residents per room separated by a curtain. Economic exigencies have kept staff-resident ratios high and marginalized those who work in these environments. A significant number of LTC staff are women in precarious job conditions, especially those who are racialized and or immigrant, which points to the undervaluing of the skills, efforts, responsibilities and working environments in these jobs.

System-level resilience and response in LTC environments reveal key areas of development with growing evidence of efficacy and effectiveness to foster and recovery. There are several features of the built environment of LTC facilities that can be altered or adapted. Key design considerations that could be adopted include: single person occupancy of a room with an attached bathroom, a flex space (e.g., an activity space with Murphy or wall beds) that may be used for overnight stay of staff, family accommodation in the resident rooms, provision of a secured outdoor space, and food and housekeeping available on site. In a few care homes with COVID-19 outbreaks, healthcare workers made the remarkable decision to stay on site 24/7 to control potential spread of infection. Also, we need to find a balance between ensuring resident safety and providing family care and emotional support. Having flexible space and design features in the facility would provide the option of overnight stay by family and staff. Availability and access to an outdoor space (therapeutic biophilia) can serve as a useful resource for isolated residents to spend time in the outdoor area by walking, sitting or gardening, and provide positive stimulation from exposure to nature. Other possible measures include: designation of isolation rooms (in facilities with all multi-occupancy rooms), staff and visitor screening, wider hallways, use of materials and finishes for flooring and countertops that limit bacterial survival and transmission and easily accessible hand washing stations (Chaudhury 2020).

Innovations in how facilities are built, located, designed, and organized (e.g., food and meal distribution) coupled with use of technologies in LTC systems, can also mitigate COVID-19 and other pandemics, as well as increase the quality of life of residents during a vulnerable stage of life. Reducing the size and number of residents in group quarters can limit the spread of a contagious disease. One development in many Western countries (Australia, Canada, Denmark, Japan, etc.) are self-contained small homes (e.g., 12–16 bed households) with clustered arrangement of rooms, activity and dining areas (Chaudhury 2020). These afford more effective infection prevention and control, responsive management of residents with dementia and more personal care interactions. Specifically, smaller group size provides the option to compartmentalize residents who might be at greater risk of infection, as well as isolate residents who are infected. While economies of scale are needed in some urban environments with large populations, a range of LTC options is needed. In conjunction with physical isolation mitigation, dedicated staffing with adequate personal protective equipment would need to be established to minimize transmission of the virus in the facility through staff (Yen et al. 2020). Beyond the possible benefit for outbreak prevention and control, there is evidence on the positive influence of small homes or household models on increasing the social engagement levels, decreasing anxiety and aggression, and supporting mobility and reduced use of psychotropic medications among residents.

Furthermore, incorporation of appropriate technology in the care home environment is another important area open to innovation. During COVID-19, some care staff have relied on remotely connecting residents with anxious and caring family members in the community. There is a also potential for easily accessible communication technology (e.g., motion or voice controlled) that can be used by residents to stay connected with family, friends and the larger community during a lockdown phase.

There are also examples of system-level responses to COVID-19 that can serve as policy changes that specifically address these gaps in service, staffing and quality of care to foster system-level resilience and response. In the US, the Seattle WA area was ground zero for COVID-19, with the first LTC outbreaks. The University of Washington Medicine's (UWM's) Post-Acute Care (PAC) Network developed and implemented a coordinated three-phase approach in reaction to surges in COVID-19 cases in these LTC environments (Kim et al. 2020). As shown in Fig. 9.1, during the initial phase of COVID-19 at which point no COVID-19 cases had been identified, emphasis was placed on communicating response plans with all facilities; identification of points of contact for tracking cases; and preparation for distribution and use of personal protective equipment. In the second "delayed" phase, at which point cases appear, response entailed increased education and training of all staff and administration; implementation of testing criteria, supplies, and increased surveillance to identify potential cases; and the isolation of COVID-19 cases among residents into an isolated "hot" wing. The final third "surge" phase, during which time COVID-19 cases were spreading rapidly, a "drop-team" comprised of MDs, RNs and disease specialists was organized by the UWM was initiated by the skilled nursing network (SNL). The drop team assessed and tested residents and staff; evaluated, triaged and organized transfer of patients to the Washington Disaster Medical Coordination Centre if needed; and notified local public health agencies. This three-phase system response strategy proved to be effective during the COVID-19 pandemic, based on control of the spread disease. However, given the different socio-environmental contexts (and government policies) across countries, regions, state/province, and municipality; and the differential

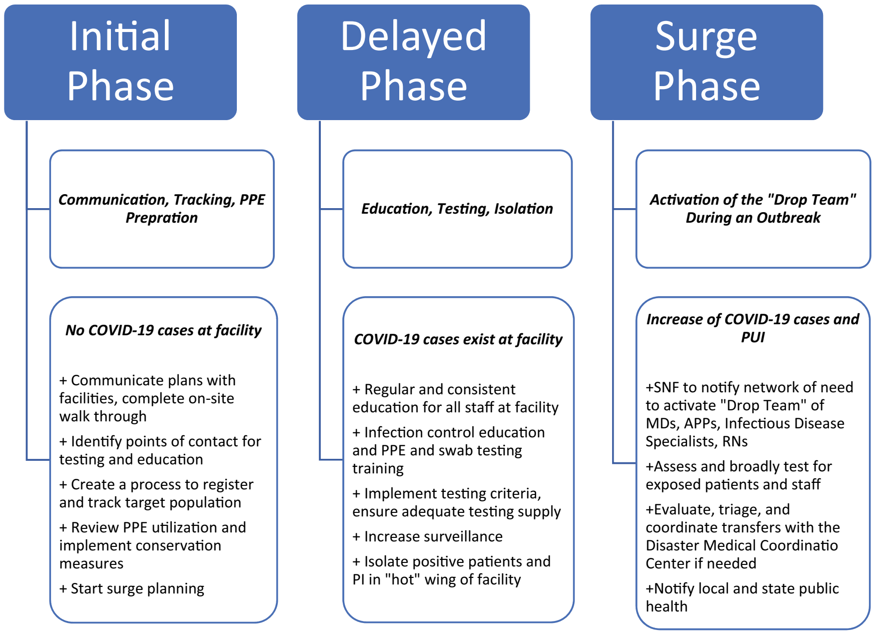

Fig. 9.1 COVID-19 Three-phase approach. *Source* Kim et al. (2020), Fig. 2

distribution and clustering of COVID-19, responses often need to be retrofitted to local conditions.

There are also unique challenges linked to the health care systems across counties. In the Canadian context, the provinces are responsible for the spectrum of public and private LTC facilities. While the federal government transfers tax funds to provinces, ultimately it is the latter that has policy jurisdiction. The case of Quebec during COVID-19 revealed problematic policy issues (Béland and Marier 2020). The underfunding of LTC, low staffing, use of private providers, and difference between regulatory practices between the public and privately funded facilities represent system-level deficiencies in preparedness that led to many LTC facilities to experience rapid spread of COVID-19 and slow response to the disease (Béland and Marier 2020).

All complex systems have strengths and weaknesses (Kasa et al., in press). Yet, the COVD-19 pandemic has revealed significant gaps in the long-term care system in most countries. While the response to COVID-19 needs to be molded to the unique circumstances and disease phase faced, there are some generic overarching guiding policy principles. Laxton et al. (2020) provide the following COVID-19 policy building blocks: (1) collaboration across health care sectors to develop and implement practical and effective solutions; (2) a “one-size-fits-all” solution does not work, especially given the differential spread and clustering of the disease across regions, states and municipalities; (3) greater federal direction, and collaboration between state/province and federal jurisdictions to address barriers to post-acute and LTC responses to COVID-19; (4) restructuring and reform to the LTC regulatory system; and (5) addressing unequal access and treatment for the populations at risk.

9.6 Risk, Resilience and Response of Older Adults in the Community

COVID-19 has also presented a range of challenges to older adults living in the community. Those living in their own homes face elevated morbidity and mortality risks. In an analysis of the 2018 US Health and Retirement Survey, Cohen and Taveres (2020) found that, compared to the LTC (nursing home) population, older adults living in the community are five-times more likely to suffer from respiratory illnesses that place them at increase risk of contracting and dying from COVID-19. In addition, older adults living in the community with respiratory disease (a major COVID-19 risk factor), compared to those without this condition, are 1.3 times more likely to live in poverty and live alone, about twice as likely to suffer from depression, and 2.9 times more likely to have four or more chronic conditions (often related to their respiratory disease (Cohen and Taveres 2020). While most older adults rate their health as good, very good or excellent and function well in their community, in absolute terms there are large segments of the older population who are at higher than average risk of COVID-19. This is, due to higher than average rates of cognitive and physical illnesses (including a majority with multimorbidity); as well as a spectrum of compromised social determinants of health, such as living alone, being an older woman, experiencing poverty, being members of a marginalized or minority/racialized group (LGBTQ2, Indigenous, Black/Hispanic background, etc.), living in rural or remote areas, and/or living in social isolation (Alonzi et al. 2020; Cohen and Taveres 2020; Henning-Smith 2020; Mueller et al. 2020; Wister and Speechley 2020). The effect of these factors on COVID-19 risk and outcomes become intensified when they occur in combination, since their intersections create negative synergetic effects on older people's risk and resilience.

Even those not directly experiencing COVID-19 face challenges meeting their basic needs such as food security, medications, maintaining a positive quality of life and health care. Physical distancing policies that keep people in their home (especially during close-down phases) or create barriers for individuals to maintain activities of daily living increase exposure risk, and related stress and coping levels for vulnerable people, especially older adults. Intrafamily spread of COVID-19 can also pose issues for older adults. Intergenerational households and families with young adults in the household are at higher risk of contracting the disease from their family members (Stokes and Patterson 2020). Older adults who rely on continuing care services (home care/support, respite care, Victoria Order of Nurses care, home repair, peer-to-peer support, non-governmental organization services, etc.)

experienced a break in formal services during the pandemic, which placed some of the care on the backs of family members and volunteer services.

Physical distancing and the higher potential negative health consequences of COVID-19 can also potentially influence levels of social isolation and loneliness, especially during stay-at-home phases of the pandemic aimed at lowering risk exposure. Tyrell and Williams (2020) term this the '*paradox of social distancing*.' On the one hand, social distancing is highly recommended for older adults given their heightened risk of contracting COVID-19 and the potential for poor recovery and mortality. On the other hand, physical distancing by its very nature can magnify the negative effects of social isolation and loneliness (Tyrell and Williams 2020).

The effects of COVID-19 risk, resilience and response on social isolation has received attention, given that the absence of social engagement and social connectedness within family, friendship and community social networks can influence health and wellness on multiple levels. Social isolation is a multifaceted concept that includes objective and subjective dimensions (Wister et al. 2019; Valtorta et al. 2016). It is typically defined as a low quantity and quality of contact with others that include the number, types and quality of social network contacts, feelings of belonging, a sense of engagement with others, feelings of loneliness, and related attributes (Courtin and Knapp 2015; Nicholson 2009). Social isolation and the subjective feelings of loneliness, have been increasingly studied in the gerontological literature, given research that have uncovered linkages between social isolation and components of health related quality of life (HRQL). For instance, research supports an increased risk of mortality, and a range of physical and mental health morbidities, including psychological well-being and quality of life (Courtin and Knapp 2015; Harasemiw et al. 2017; Leigh-Hunt et al. 2017). Additionally, social isolation has been associated with lower access to health care services, and lower health care utilization in older age, health behaviors that are needed to protect and recover during a pandemic (Newall et al. 2015).

The research on social isolation and aging has led researchers to hypothesize that the gero-pandemic physical distancing policies would exacerbate the deleterious effects of social isolation. However, in a recent longitudinal study of COVID-19 and perceptions of loneliness across age groups, Luchetti et al. (2020) found that there were no statistically significant mean-level changes in loneliness across the three assessments during the pandemic. In addition, participants in the study reported increased support and lower isolation between baseline and the follow-up period. Also, older adults had lower levels of loneliness compared to younger age groups. While older adults reported higher loneliness during the acute phase of the outbreak, their loneliness leveled off after the stay-at-home orders in March 2020. The unexpected findings were explained by the authors as a form of resilience in response to COVID-19 (Luchetti et al. 2020). While it might be possible that older adults cope and adapt better to COVID-19 physical distancing restrictions than younger age groups, additional research is needed to make definitive conclusions. Furthermore, the above study used a measure if loneliness, rather than social isolation or a comprehensive social isolation index; and did not examine sub-groups of vulnerable older adults, who might have high risk levels.

In a similar manner to LTC, the community care system, with home care at the fulcrum, is fragmented within and across state/provincial and regional jurisdictions in terms of funding, organization, and integration. The COVID-19 pandemic has exposed several inadequacies of the system. For instance, Canada spends only 15% of its public health funds for home care, far below other countries such as Denmark, Sweden, and France (Wister 2019). Furthermore, home care systems are structured in a way that does not meet the changing and complex health care needs of a rapidly aging population. Issues of staff training, variability in matching home care workers and older people, waitlists, case management and personal protective equipment have surfaced.. Yet, home care can foster resilience and life satisfaction, and decrease loneliness and life stress, under optimal conditions (Kadowaki et al. 2015).

9.7 Ageism and Intergenerational Tensions as Barriers to Resilient Responses to a Gero-pandemic

The COVID-19 gero-pandemic has resulted in tensions in disciplinary and aging-related public health responses to the disease. Gerontologists, epidemiologists, medical researchers, public health and other health researchers have made significant contributions to the knowledge-base surrounding COVID-19. Advances in patterns of prevalence, risk factors, and a variety of age-related characteristics of the disease has raised the profile of aging issues connected to the crisis (Wister in press). System-level responses to COVID-19 have raised policy issues related to aging, such as post-acute, long-term and continuing care policies (Béland and Marier 2020; Kim et al. 2020; Laxton et al. 2020); the need to emphasize and enhance intergenerational solidarity to support physically distanced older adults (Ehn and Wahl 2020); and retrofitting the range of aging-related programs and services to meet the unique mental and physical needs of older people during the gero-pandemic (Monahan et al. 2020). Conversely, there has also been a number of negative responses to COVID-19 risk and response, some of which have been intended and some of which are unintended. For instance, there has been a backlash of younger and working populations who believe that the susceptibility and seriousness of COVID-19 for themselves is lower than for older adults, and that societal responses (i.e., closing the economy and society at large) have been too severe (Wister, in press). This has resulted in exacerbating intergenerational conflicts, for example, the "ok boomer" movement has been applied to COVID-19 including hash tags such as "the boomer remover" that has pitted younger and older generations against each other. Other individuals and groups have expressed the view that the COVID-19 pandemic is a "senior's problem," propagating ageism (Bergman et al. 2020; Ehn and Wahl 2020; Monahan et al. 2020; Morrow-Howell et al. 2020; Previtali et al. 2020; Wister and Speechley 2020).

Ageism was originally coined by Butler (1969), who defined it as a process of systematic stereotyping of and discrimination against people because of biological/

physiological attributes or merely because they are old. According to Bytheway (2005), there is both *individual* ageism, the acceptance of negative feelings and beliefs that influence our thinking and behavior about older adults, and *institutionalized* (or structural) ageism, as expressed in legislation and mass media, all of which can lead to age-related social and economic inequalities across society. Individual and institutionalize ageism affect how older people are treated in terms of disease risk and responses, as well as relationships among individuals that can directly affect self-image, self-esteem, self-efficacy and resilience. Indeed, resilience to the gero-pandemic by older adults can be eroded through the intensification of tensions between younger and older populations, some segments of society questioning the value and contributions that older people make, and by creating new social barriers to meeting public health goals in an aging society (Wister in press).

In a small study of the moderating effects of ageism in the previously established association between health worries and anxiety among older adults during the COVID-19 pandemic, Bergman et al. (2020) found evidence of the role of *COVID-19 ageism*. The authors found that both health worries and ageism were positively associated with anxiety symptoms. Furthermore, they demonstrated that the connection between health worries and anxiety symptoms was more pronounced among older adults with high ageism levels, thus establishing that ageism and health worries interact to affect anxiety (Bergman et al. 2020). These finding are particularly daunting during COVID-19, since health worries have become exacerbated. High levels of anxiety can lower the ability of older people to be resilient, especially in a crisis (Sells et al. 2009; Wister et al. 2018). Although further study is needed, this early research provides initial evidence of the role of ageism on psycho-social adaptive processes during this gero-pandemic.

Covid-19 ageism has also led older people and society in general to devalue the contribution that older people have and continue to make. This has led to discussions of rationalizing of health services (e.g., age cut-offs for ventilators in acute COVID-19 care) based on age rather than need (Bergman et al. 2020; Ehn and Wahl 2020; Monahan et al. 2020; Wister and Speechley 2020). Finally, the politicization of COVID-19 (e.g., the downplaying of seriousness and spread of the disease for the younger and working age population to rationalize early opening the economy), is another context in which ageism is manifested. Understanding the COVID-19—ageism nexus requires additional studies into this complex, multi-layered social problem, and moreover, the identification and implementation of positive responses to this problem. Along these lines, Ehn and Wahl (2020) have identified six propositions to reduce ageism during the gero-pandemic (see below).

Six Propositions Against Ageism During the COVID-19

Proposition 1: Older adults are highly heterogeneous–their health and functioning is better than negative stereotypes suggest.

Proposition 2: Age limits for intensive care and other forms of medical care are inappropriate and unethical.

Proposition 3: Mass deficit views of old age are dangerous to older citizens and societies at large–intergenerational solidarity must be strengthened.

Proposition 4: Resisting the assumption of a paternalistic attitude toward older adults in the crisis is important.

Proposition 5: The COVID-19 crisis demands fostering the use of modern information and communication technologies among older adults.

Proposition 6: The COVID-19 crisis not only demands the best of virology but also the best of gerontology for policy guidance and understanding the consequences of the crisis at large.

Source: Ehn and Wahl (2020).

9.8 The Technological and Human Interface as a Response to COVID-19

The COVID-19 gero-pandemic has resulted in rapid system-level responses across the full spectrum of jurisdictions and socio-ecological domains. This includes development, implementation and evaluation of technological and human-based innovations (Wister, in press). During the pandemic, the diffusion of technologies, including retrofitting those in existence and the development of new ones, has occurred at break-neck speed. These cover a wide range of applications, including bio-tech companies scrambling to produce and distribute effective and safe COVID-19 vaccine(s); production of ventilators for acute care of COVID-19 patients; rapid production and distribution of personal protective equipment; smart-phone apps to support contact tracing; improved versions of remote communication programs to support more diverse work and social contact needs (e.g., Zoom, WebEx, Vidyo, Skype, etc.); and coordinated/integrated COVID-19 case tracking. Other types of innovation have included new applications or adaptations of existing technology, such as the use of smart phone, tablets, or computers with LTC residents so that they may see and speak to family and friends.

Technological developments have also been used to address challenges imposed by lock-down and physical distancing policies (Morrow-Howell et al. 2020). While within-household family members have provided core social support functions, those living outside of the household ‘bubble,’ including family members, friends, and community services, have been forced to make adaptations to provide supports to older adults and their families to meet basic needs in a safe manner. This has been particularly challenging for the most vulnerable older adults, who require greater levels of support with instrumental and basic activities of daily living. This is especially the case for older adults with compromised physical and/or mental health, such as those living in LTC, assisted living or supportive housing, and those living alone in the community with low or below optimum levels of social determinants of health (see above). Technological solutions have become an important resource to assist people to remain connected to others and obtain necessary products and services during the pandemic. Yet, there remains a *digital divide* (unequal access to technology due to social determinants of health, poor technological literacy, and/or lack of Internet, etc., such that many older adults do not have access to or the ability to use smart phones, tablets, or computers (Wister, in press). For some of these individuals, older “low tech” solutions like the telephone may be more effective in reaching the most vulnerable older adults, in particular those who are poor or socially/physically isolated. For others, technology access, literacy and learning may be needed in order to fill the technological gap. For instance, during the pandemic some libraries loaned tablets to isolated older adults to access Internet-supported communication platforms and provided basic technical assistance by phone.

Given that some older people do not have internet access, own a suitable technological device, lack fundamental skills, or have physical or mental health challenges that prevent access, there has been a heightened need to support vulnerable older adults. The maintenance of social support systems during adversity is a fundamental component of health promotion and resilience in older age (Sells et al. 2009).

Human-based approaches have filled some of the gaps left by the digital divide. Many individuals of all ages, including older adults themselves, invest enormous time and energy into volunteering, intergenerational assistance, and other unpaid activities. These include voluntary involvement in organizations and community groups or through informal contributions in the form of caregiving, social support, and donating money to family, friends, or neighbours (Turcotte and Schellenberg 2007; National Seniors Council 2010). *Community-level resilience* in the form of helping behavior has been shown to be a pervasive social resource, both separately and in combination with technological innovations.

During the COVID-19 crisis, volunteering has become even more crucial means to reach older adults living in the community who are the most isolated, marginalized, disadvantaged and/or frail. Volunteer resources can fill the technological gap, and be the conduit between technologies and accessing needed supports during a pandemic. A plethora of organizations serving older adults (e.g., seniors centres, non-governmental organizations, and community neighbourhood houses) have adapted their programs and services, using volunteers to contact clients through telephone and Internet, organize delivery of groceries and medicine, and to volunteer to deliver themselves (Wister, in press). Many organizations have reported that their volunteer base increased substantially during the pandemic.

Additionally, informal caregivers have faced new challenges during the recent pandemic. Those living with an older adult have had to assume additional duties when formal services are unable to function effectively (Stokes and Patterson 2020). Similarly, those living outside of the home have delivered food and medicine to the homes of older family members, if they are unable to do so themselves. Invariably, the fear of infecting loved ones with COVID-19, given that it can be asymptomatic, has infused an additional layer of complexity, fear, and uncertainty to the caregiver role (Stokes and Patterson 2020). Yet, the adaptability of the informal support system during the more serious periods of the crisis is remarkable in many instances, revealing resilience in places in which we were not aware.

9.9 Conclusion

In response to the current pandemic, societies, states/provinces, regions and local municipalities have adopted health policies that have been organized for testing and isolating COVID-19 cases, acute and long-term care response and adaptation, and system-level closing and opening phases. These include: visitation restriction and health worker disease testing, personal protection and facility work stability in LTC; physical distancing; washing hands; masks and personal protective equipment; limitations on the size of gatherings; sanitation policies; and so forth (see Government of Canada 2020). Surveillance systems (e.g., contact tracing) are at the core of public health approaches to COVID-19 in order to map the spread of the disease and the degree to which the public adheres to policies. This is an excellent example of how healthy public policy can lower risk, and enhance resilience, during a pandemic. However, given differences in approaches, disease prevalence and incidence, and available resources, some health jurisdictions, states/provinces, and countries have had better and more effective system-level preparedness and action to the pandemic than others. Most older adults are healthy and socially connected; however, in the COVID era, like everyone else, they face the adverse effects of the disease (Morrow-Howell 2020). These tend to be exacerbated among older adults, especially those with pre-existing conditions or other characteristics that place them at higher risk and lower resilience (Shahid et al. 2020). Moving forward, considerably more research and knowledge is needed to forge a successful pathway out of the current pandemic and result in higher level preparedness for the next. In addition to epidemiological complexities in obtaining accurate data on COVID-19, societies face a number of unequally distributed public health challenges. Many pre-pandemic social problems that older people face, such as lower access to health services, ageism, social isolation, loneliness, anxiety, depression, food insecurity, elder abuse, racial/ethnic marginalization and spousal caregiving burden, become magnified during COVID-19. Understanding the interconnections among risk, vulnerability, response, recovery and resilience has potential to identify major areas of inquiry and knowledge for those interested in public health responses to a pandemic, especially from a salutogenic, strength-based perspective (Antonovsky 1996). As with many forms of adversity, the current pandemic provides not only new challenges and problems, but also new opportunities and solutions that cut across individuals, systems, and the globe.

References

Alonzi S, La Torre A, Silverstein MW (2020) The psychological impact of preexisting mental and physical health conditions during the COVID-19 pandemic. Psychol Trauma 12(S1):S236–S238

Andrew MK, Searle SD, McElhaney JE et al (2020) COVID-19, frailty and long-term care: Implications for policy and practice. J Infect Develop Countries 14(5):428–432. https://doi.org/10.3855/jidc.133003

Antonovsky A (1996) The salutogenic model as a theory to guide health promotion. Health Promot Int 11(1):11–18

Barber S, Kim H (2020) COVID-19 Worries and behavior changes in older and younger men and women. J Gerontol: Ser B:gbaa068. https://doi.org/10.1093/geronb/gbaa068

Béland D, Marier P (2020) COVID-19 and long-term care policy for older people in Canada. J Aging Soc Policy 32(4–5):358–364. https://doi.org/10.1080/08959420.2020.1764319

Bergman YS, Cohen-Fridel S, Shrira A, Bodner E, Palgi Y (2020) COVID-19 health worries and anxiety symptoms among older adults: the moderating role of ageism. Int Psychogeriatr. https://doi.org/10.1017/S1041610220001258

Blagosklonny M (2020) From causes of aging to death from COVID-19. Aging 12(11):1004–1021

Bruine de Bruin W (2020) Age differences in COVID-19 risk perceptions and mental health: Evidence from a National U.S. Survey Conducted in March 2020. J Gerontol: Ser B. https://doi.org/10.1093/geronb/gbaa074

Butler R (1969) Ageism: another form of bigotry. Gerontologist 9(3):243–246

Bytheway B (2005) Ageism and age categorization. J Soc Issues 61(2):361–374

CDC (2020) COVID-19 Hospitalizations and deaths by age. https://www.cdc.gov/coronavirus/2019-ncov/covid-data/investigations-discovery/hospitalization-death-by-age.html

Chaudhury H (2020) Lifting the curtain on long-term care in the face of COVID-19: sobering realities and a time for reform. In: GRC New. Special COVID-19 Edition. Gerontology Research Centre, Vancouver

Clark P, Burbank P, Greene G et al (2011) What do we know about resilience in older adults? An exploration of some facts, factors, and facets. In: Resnick B, Gwyther L, Roberto K (eds) Resilience in aging: concepts, research and outcomes. Springer, New York, NY, pp 1–14

Cohen M, Tavares J (2020) Who are the most at-risk older adults in the COVID-19 era? It's not just Those in Nursing Homes. J Aging Soc Policy 32(4–5):380–386. https://doi.org/10.1080/08959420.2020.1764310

Courtin E, Knapp M (2015) Social isolation, loneliness and health in old age: a scoping review. Health Soc Care Commun. https://doi.org/10.1111/hsc.12311

Ehni H-J, Wahl H-W (2020) Six propositions against ageism in the COVID-19 pandemic. J Aging Soc Policy 32(4–5):515–525. https://doi.org/10.1080/08959420.2020.1770032

Employment and Social Development Canada (2019) Report on housing needs of seniors. Ottawa, ON. https://www.canada.ca/en/employment-social-development/corporate/seniors/forum/report-seniors-housing-needs.html.

Fisman DN, Bogoch I, Lapointe-Shaw L, McCready J, Tuite AR (2020) Risk factors associated with mortality among residents with Coronavirus Disease 2019 (COVID-19) in long-term care facilities in Ontario, Canada. JAMA Netw Open 3(7). https://doi.org/10.1001/jamanetworkopen.2020.15957

Gardner W, States D, Bagley N (2020) The coronavirus and risks to the elderly in long-term care. J Aging Soc Policy 32(4–5):310–315. https://doi.org/10.1080/08959420.2020.1750543

Government of Canada. (2020). Coronavirus disease (COVID-19). Retrieved 14 May 2020 from https://www.canada.ca/en/public-health/services/diseases/coronavirus-disease-covid-19.html.

Hado E, Feinberg LF (2020) Amid the COVID-19 pandemic, meaningful communication between family caregivers and residents of long-term care facilities is imperative. J Aging Soc Policy 32 (4–5):410–415. https://doi.org/10.1080/08959420.2020.1765684

Harasemiw O Newall N, Shooshtari S, Mackenzie C, Menec V (2017) From social integration to social isolation: the relationship between social network types and perceived availability of social support in a national sample of older Canadians. Res Aging, 1–25. https://doi.org/10.1177/0164027517734587

Henning SC (2020) The unique impact of COVID-19 on older adults in rural areas. J Aging Soc Policy 32(4–5):396–402. https://doi.org/10.1080/08959420.2020.1770036

Kadowaki L, Wister A, Chappell N (2015) Home care needs and their influence on life satisfaction, loneliness and perceived life stress. Can J Aging 34(1):75–89. https://doi.org/10.1017/S0714980814000488

Kim G, Wang M, Pan H, Davidson G, Roxby A, Neukirch J, …, Ong T (2020) A health system response to COVID-19 in long-term care and post-acute care: a three-phase approach. J Am Geriatr Soc (JAGS) 68(6):1155–1161

Klasa K, Galaitsi S, Trump B, Linkov I (2021a) Science and practice of resilience: disaster systems applications to aging model development. In: Wister A, Cosco T (eds) Resilience and aging: emerging science and future possibilities. Springer, New York, pp 53–80

Klasa K, Galaitsi S, Wister A, Linkov I (2021b) System models for resilience in gerontology: application to the COVID-19 pandemic. BMC Geriatr 21:51. https://doi.org/10.1186/s12877-020-01965-2

Laxton CE, Nace DA, Nazir A (2020) Solving the COVID-19 crisis in post-acute and long-term care. JAMDA 21:885–887

Leigh-Hunt N, Bagguley D, Turner V, Turnbull N, Valtorta N, Caan W (2017) An overview of systematic reviews on the public health consequences of social isolation and loneliness. Public Health 152:157–171. https://doi.org/10.1016/j.puhe.2017.07.035

Linkov I, Kott A (2019) Fundamental concepts of cyber resilience: Introduction and overview. Cyber resilience of systems and networks. Springer, New York, pp 1–25

Liu Y, Gayle A, Wilder-Smith A, Rocklöv J (2020) The reproductive number of COVID-19 is higher compared to SARS coronavirus. J Travel Med 27(2):taaa021. https://doi.org/10.1093/jtm/taaa021

Luchetti M, Lee JH, Aschwanden D, Sesker A, Strickhouser JE, Terracciano A, Sutin AR (2020) The trajectory of loneliness in response to COVID-19. Am Psychol. https://doi.org/10.1037/amp0000690

Mauvais-Jarvis F (2020) Aging, male sex, obesity, and metabolic inflammation create the perfect storm for COVID-19. Diabetes (New York, N.Y.):Dbi190023.

McMichael TM, Clark S, Pogosjans S et al (2020) COVID-19 in a long-term care facility—King County Washington, February 27-March 9, 2020. US Department of Health and Human Services/Centers for Disease Control and Prevention: Morbidity and Mortality Weekly Report, vol 69(12)

Mitra AR, Fergusson NA, Lloyd-Smith E et al (2020) Baseline characteristics and outcomes of patients with COVID-19 admitted to intensive care units in Vancouver, Canada: a case series. CMAJ 192(26):E694-701. https://doi.org/10.1503/cmaj.200794

Monahan C, Macdonald J, Lytle A, Apriceno M, Levy SR (2020) COVID-19 and ageism: how positive and negative responses impact older adults and society. Am Psychol. https://doi.org/10.1037/amp0000699

Morrow-Howell N, Galucia N, Swinford E (2020) Recovering from the COVID-19 pandemic: a focus on older adults. J Aging Soc Policy 1

Mueller AL, McNamara MS, Sinclair DA (2020) Why does COVID-19 disproportionately affect older people? Aging 12(10):9959–9981

National Seniors Council (NSC) (2010) National Seniors Council on Volunteering among seniors and positive and active aging. Minister of Human Resources and Skills Development, and the Minister of the State (Seniors), Ottawa

Newall N, McArthur J, Menec V (2015) A longitudinal examination of social participation, loneliness, and use of physician and hospital services. J Aging Health 27(3):500–518

Nicholson NE Jr (2009) Social isolation in older adults: An evolutionary concept analysis. J Adv Nurs 65(6):1342–1352

Ong AD, Bergeman CS, Bisconti TL, Wallace KA (2006) Psychological resilience, positive emotions, and successful adaptation to stress in later life. J Pers Soc Psychol 91(4):730–749

Previtali F, Allen LD, Varlamova M (2020) Not only virus spread: The diffusion of ageism during the outbreak of COVID-19. J Aging Soc Policy 32(4–5):506–514. https://doi.org/10.1080/08959420.2020.1772002

Renu K, Prasanna P, Valsala Gopalakrishnan A (2020) Coronaviruses pathogenesis, comorbidities and multi-organ damage—a review. Life Sci (1973) 255:117839

Richardson G (2002) The metatheory of resilience and resiliency. J Clin Psychol 58(3):307–321

Rootman I et al (eds) (2012) Health promotion in Canada: critical perspectives on practice. Canadian Scholars' Press Inc., Toronto, ON

Sells D et al (2009) Cascading crises, resilience, and social support within the onset and development of multiple chronic conditions. Chronic Illn 5(2):92–102. https://doi.org/10.1177/1742395309104166

Shahid Z, Kalayanamitra R, McClafferty B, Kepko D, Ramgobin D, Patel R, … Jain R (2020) COVID-19 and older adults: What we know. J Am Geriatr Soc 68(5):926–929

Shippee T, Akosionu O, Ng W, Woodhouse M, Duan Y, Thao M, Bowblis J (2020) COVID-19 pandemic: Exacerbating racial/ethnic disparities in long-term services and supports. J Aging Soc Policy 32(4–5):323–333. https://doi.org/10.1080/08959420.2020.1772004

Stokols D (1992) Establishing and maintaining healthy environments: toward a social ecology of health promotion. Am Psychol 47(1):6–22

Stokes JE, Patterson SE (2020) Intergenerational relationships, family caregiving policy, and COVID-19 in the United States. J Aging Soc Policy 32(4–5):416–424. https://doi.org/10.1080/08959420.2020.1770031

Valtorta N, Kanaan M, Gilbody S, Hanratty B (2016) Loneliness, social isolation and social relationships: what are we measuring? A novel framework for classifying and comparing tools. BMJOpen 6:e010799. https://doi.org/10.1136/bmjopen-2015-010799

Turcotte M, Schellenberg G (2007) A portrait of seniors in Canada. Statistics Canada, Ottawa

Tyrrell CJ, Williams KN (2020) The paradox of social distancing: implications for older adults in the context of COVID-19. Psychological Trauma 12(S1):S214–S216

Ungar M (2008) Resilience across cultures. Br J Soc Work 38:218–235

USGCRP (2020) US Global Change Research Program Glossary. Retrieved September 23, 2020. https://www.globalchange.gov/climate-change/glossary

Windle G (2012) The contribution of resilience to healthy ageing. Perspect Public Health 132 (4):159–160. https://doi.org/10.1177/1757913912449572

Wister A (2019) Aging as a social process: Canada and beyond. Oxford University Press, Don Mills ON

Wister A (2021) Multimorbidity resilience: conceptual, theoretical, and measurement development. In: Wister A, Cosco T (eds) resilience and aging: emerging science and future possibilities. Springer, New York, pp 81–106

Wister A (in press) Health promotion and aging during a pandemic: risk, resilience and COVID-19." In: Rootman I, Edwards P, Levasseur M, Grunberg F (eds) Health of older adults: the canadian experience. Canadian Scholars Press Inc, Toronto, ON

Wister A, Cosco T (2021) Introduction: perspectives of resilience and aging. In: Wister A, Cosco T (eds) resilience and aging: emerging science and future possibilities. Springer, New York, pp 1–25

Wister A, Speechley M (2020) Editorial—COVID-19: Pandemic risk, resilience, and possibilities for aging research. Can J Aging, Forthcoming

Wister A, Coatta K, Schuurman N et al (2016) A lifecourse model of multimorbidity resilience: Theoretical and research developments. Int J Aging Hum Dev 82(4):290–313. https://doi.org/10.1177/0091415016641686

Wister A, Lear S, Schrumann N, MacKey D, Mitchell B, Cosco T, Fyffe I (2018) Development and validation of a multi-domain multimorbidity resilience index for an older population: results from the baseline Canadian Longitudinal Study on Aging. Biomed Cent (BMC) Geriatr 18(1):1–13. https://doi.org/10.1186/s12877-018-0851-y

Wister A, Cosco T, Mitchell B, Menec V, Fyffe I (2019) Development and concurrent validity of a composite social isolation index for older adults using the Canadian Longitudinal Study on Aging. Can J Aging 38(2):180–192. https://doi.org/10.1017/S0714980818000612

Wister A, Cosco T, Mitchell B, Fyffe I (2020) Health behaviors and multimorbidity resilience among older adults using the Canadian Longitudinal Study on Aging. Int Psychogeriatr 32(1): 119–133

Xu L, Mao Y, Chen G (2020) Risk factors for 2019 novel coronavirus disease (COVID-19) patients progressing to critical illness: a systematic review and meta-analysis. Aging 12(12): 12410–12421

Yen M-Y, Schwartz J, King C-C, Lee C-M, Hsueh P-R (2020) Recommendations for protecting against and mitigating the COVID-19 pandemic in long-term care facilities. J Microbiol Immunol Infect 53:447–453. https://doi.org/10.1016/j.jmii.2020.04.003

Chapter 10
The Impact of "Flatten the Curve" on Interdependent Economic Sectors

Joost Santos and Sheree Pagsuyoin

Abstract The COVID-19 pandemic has severely disrupted the operation of many economic sectors and challenged the capacity of healthcare systems. The "flatten the curve" expression has been widely used recently. To flatten the curve means to slow down the rate of disease transmission so as not to strain limited healthcare resources. In the absence of vaccines, the scientific community has urged for the implementation of nonpharmaceutical interventions (NPIs) to flatten the curve. This paper applies the Leontief input-output model (IO) to assess the impact of COVID-19 on the U.S. economy. The model uses publicly available IO data coupled with epi curves to estimate the ripple effects of workforce disruptions across interdependent sectors of the economy. The epi curve for the U.S. is characterized by an uptick of cases after the 2020 Memorial Day weekend, which is used as the baseline scenario. The paper then explores a mitigated scenario and evaluates the extent to which a flattened curve can effectively reduce the economic losses incurred by various sectors. The results of this study can be used to formulate policies for implementing NPIs, as well as to identify potential solutions to curb the impact of disasters, like the COVID-19 pandemic, on the workforce and the economy.

Keywords Input–output model · Disaster risk management · Flatten the curve · Workforce modeling · COVID-19 pandemic

J. Santos (✉)
Department of Engineering Management and Systems Engineering, George Washington University, Washington, DC, USA
e-mail: joost@gwu.edu

S. Pagsuyoin
Department of Civil and Environmental Engineering, University of Massachusetts Lowell, Lowell, USA

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_10

10.1 Introduction

Time and again, history has taught us that disease outbreaks can wreak havoc on healthcare systems and economies. The 1918 influenza, the most catastrophic pandemic in the last century, claimed an estimated 50–100 million lives worldwide (Taubenberger and Moren 2006). The 2003 severe acute respiratory syndrome (SARS) epidemic resulted in over 8,000 cases and 700 deaths (WHO 2003), and over $30 billion in disproportionate economic losses (Peiris et al. 2008) due to the ensuing disruptions to travel and tourism (Smith 2006). The ongoing global opioid epidemic exerts tremendous societal burdens; in the United States alone, the epidemic causes nearly 50,000 overdose fatalities (CDC 2018a; b), millions in hospital visits (AHRQ 2019), and tens to hundreds of billion dollars in socioeconomic costs (Florence et al. 2016; CEA 2017) each year. The ongoing COVID-19 pandemic has caused severe global impacts; as of September 14, 2020, over 29.4 million total cases and 931,000 deaths have been recorded worldwide (Worldometer 2020). Recent data from the United Nations indicate that COVID-19 has resulted in significant losses to global production sectors, with middle-income countries experiencing an average of 22–24% loss in their index of industrial production between December 2019 and April 2020 (UNIDO 2020).

In the time of COVID-19, the rise in popularity of the phrase *flatten the curve* is associated with population-centric interventions designed to influence the progression of the disease trajectory. In epidemiology context, to *flatten the curve* denotes efforts to reduce the daily disease cases to a level that is manageable for healthcare providers. Its graphical representations—such as the Center for Disease Control's *flatten the curve* graph (CDC 2007) and its subsequent modifications—allow for visualization of the rate and severity of disease outbreaks (CDC 2017), the capacity of healthcare systems (Harris 2020), and the effects of control interventions (London and Milan 2020). Another extension to the "flatten the curve" graphic is "raise the line" in which the intent is to increase the healthcare system capacity to catch up with the surge in hospitalizations (Barclay et al. 2020). Figure 10.1 reproduces the combined "flatten the curve" and "raise the line" concepts.

The epidemic curve, or *epi curve*, is another visualization tool that has been used extensively in providing regional or local health updates. An epi curve is a normalized plot of disease cases (y-axis) over time (x-axis). A disease' *attack rate* can be calculated by normalizing the number cases against population size. Attack rate data from epi curve can be used to determine the disruptions caused by the disease on various workforce sectors (Santos 2020), or examine the effects of interventions on the workforce.

Disease outbreaks, like COVID-19, disrupt the workforce sector (e.g., via absenteeism, Santos et al. 2014) and healthcare systems (e.g., via overburden, Sadique et al. 2008, and program interruptions, Elston et al. 2016), causing direct and ripple effects within and across economies (El Haimar and Santos 2015; Huber et al. 2018). In some cases, disease outbreaks may preempt, coincide with, or follow other disasters, consequently magnifying their adverse effects. For example, during

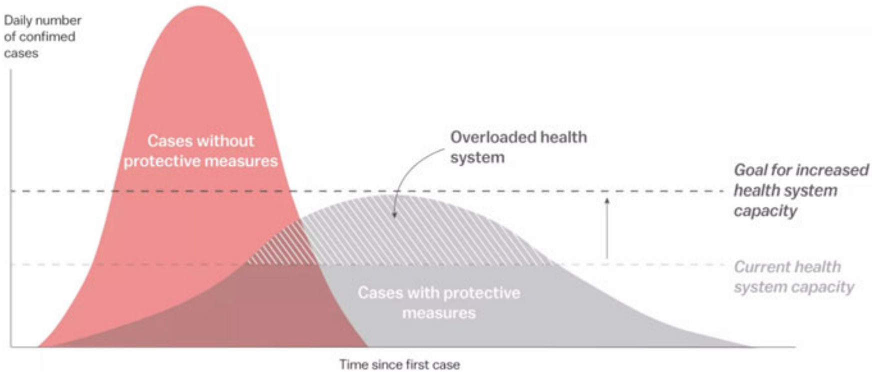

Fig. 10.1 Raising the line while flattening the curve (Barclay et al. 2020) (Note that the "raise the line" extension has been attributed by the Vox article to Kumar Rajaram of UCLA.)

Hurricane Katrina, sewage contamination of water systems occurred, resulting in increased incidences of diarrhea (Watson et al. 2007). Healthcare workers, police officers, and volunteers who came in contact with sick patients also became infected (Morantz 2005). In the United States, the onset of the COVID-19 pandemic coincided with two ongoing epidemics, the opioid epidemic (Alexander et al. 2020) and the vaping epidemic among adolescents (Jones and Salzman 2020). The pandemic increased the vulnerability of substance abuse patients through increased risks for respiratory infections and associated complications, impediments to healthcare delivery due to social distancing measures (Volkow 2020), and increased risks for relapse and overdose due to the isolation (Weiner 2020).

In examining the criticality of the workforce in disaster risk management, Santos et al. (2020) argued that the workforce should be held at an equal level of importance as critical infrastructures when preparing for disasters and emergencies. Disasters affect the employees' ability to report to work in a variety of ways, either directly as a result of the disaster (e.g., damaged dwelling) or as a secondary result of disruptions to needed services such as transportation and electric power. Workforce absenteeism during disease outbreaks can occur due to personal illness or caring for sick family members. In workforce-related emergency and preparedness planning, the goal is to minimize the negative impacts of absenteeism. Previous studies have focused on understanding the barriers to employees' return to work (see for examples, Thanner et al. 2011; Considine et al. 2011) and exploring different strategies to reduce worker absenteeism (Garrett et al. 2009) and sustain workforce capacity (Fraher et al. 2020; Schwartz et al. 2020).

Curbing the spread of diseases can be achieved through pharmaceutical (medication, vaccination) or non-pharmaceutical interventions (NPIs). In the case of disease resurgence for which vaccinations are readily available (e.g., smallpox), combining containment (isolation of infected patient) with targeted vaccination campaigns can be highly effective even in dense urban areas (Eubank et al. 2004). However, for novel diseases such as COVID-19 for which vaccines are not available at the time of the outbreak, flattening the curve can only be achieved by adopting NPIs. In addition to containment, NPI measures are broadly categorized as either suppression or mitigation. The distinction between these two categories relates to an epidemiologic term, *basic reproduction number* (R_0) which indicates the continued spread ($R_0 > 1$) or end ($R_0 < 1$) of an outbreak (Diekmann et al. 1990). For context and comparison, the estimated range of R_0 values for SARs-CoV-2 is 1.4–5.7 (WHO 2020a, b; Zhao et al. 2020; Sanche et al. 2020) and 12–18 for measles (Guerra et al. 2017). In suppression, the aim is to reduce the R_0 value to below 1 (i.e., stop disease transmission). In this sense, suppression measures tend to be stricter and more aggressive; examples include travel bans, lockdowns, household quarantines, and school closures (Kaseem 2020; Trump et al. 2020). In contrast, mitigation seeks to slow but not necessarily stop the spread of the disease (R_0 still above 1). Mitigation measures include social distancing, wearing face coverings, and hygiene practices such as handwashing and cleaning of high contact surfaces. More expansive examples and discussions on the distinctions between suppression and mitigation NPIs have been presented elsewhere (see for examples, Kayi and Sakarya 2020; Kassem 2020). Nonetheless, in both suppression and mitigation, the main goal is to lower infections to prevent overwhelming the capacity of healthcare systems at any given time. It is important to note that NPI strategies for COVID-19 introduce a new dimension to outbreak-related workforce absenteeism, one that is not due to worker or family illness, but is enforced through regulations (business closure, travel bans, lockdowns).

In the present study, we examine the time-varying effects of mitigation measures on interdependent workforce sectors and associated economic losses during a pandemic. The remainder of the paper is organized as follows. Section 2 discusses the input-output method and its dynamic inoperability extension to assess workforce disruptive events, such as pandemics, and their ripple effects to the interdependent sectors of the economy. Section 3 presents a case study of the United States using a baseline epidemic curve and compares it to a mitigated scenario. Finally, Sect. 4 presents the conclusions of the paper and provides areas for future study.

10.2 Methods

As with any disasters, the issues surrounding disease pandemics such as the current COVID-19 are complex and multifaceted in nature. Santos et al. (2020) have developed the WEIGHT framework to identify the dimensions of disaster risk management, which stands for: (i) workforce/population, (ii) economic, (iii) infrastructure, (iv) geography, (v) hierarchy, and (vi) time. The current paper considers these dimensions to assess the consequences arising from the COVID-19 pandemic. Our analysis places emphasis on estimating the time-varying economic losses resulting from pandemic-related workforce disruptions. Furthermore, this paper investigates the extent to which mitigation measures can improve the recovery pace, which in turn reduces the projected economic losses.

Previous studies have estimated the impact of pandemics on the workforce. For example, Ferguson et al. (2006) have documented the significant impact of an influenza pandemic on workforce absenteeism to as high as 40%. For the case of the relatively mild 2009 H1N1 pandemic, Santos et al. (2009) estimated that a 15% attack rate on the Commonwealth of Virginia could translate to a loss of $5.5 billion. Thus, analyzing the impact of workforce-debilitating events is an important area of investigation, such as in the case of the COVID-19 pandemic that many nations across the world are struggling to mitigate. Most disaster risk management models focus on critical infrastructure systems; nonetheless, equitable attention ought to also be placed on the workforce. For disease pandemics, the criticality of the workforce is further amplified. This is because pandemics directly disrupt the workforce more so than physical infrastructure systems, in contrast to natural disasters that inflict direct damage to physical systems. To some extent, a paradigm shift in thinking is warranted to reflect on the equitable balance and attention to both workforce and infrastructure systems. In recent years, literature on disaster risk management have placed disproportionately heavier attention to physical infrastructure systems.[1] While there is nothing wrong with an infrastructure-centric analysis approach, a more robust approach is to simultaneously evaluate the importance and coupling across workforce and infrastructure systems (Table 10.1).

In this work, we will apply and extend the economic input-output (IO) model to compare and contrast a baseline pandemic scenario versus a mitigated scenario. Leontief won the 1973 Nobel Prize in Economics for the IO model that is capable of: (i) accounting the transactions across interdependent sectors of the economy and, (ii) evaluating the impact of demand/supply changes on the economy (Leontief 1936). Discussions of the theory and applications of Leontief’s IO model are presented in Miller and Blair (2009). Supporting IO data sets are collected on a regular basis by many nations, along with social accounting matrices that can support the implementation of more sophisticated models. The computable general equilibrium, for example, can be viewed as an extended version of the IO models that allows for the relaxation of linearity (e.g., inclusion of substitution and price elasticity). IO and CGE have been used in conjunction with simulation and optimization tools to enable effective resource allocation across the sectors and regions, and also to aid in formulation of a wide range of economic policies. Recently, there has been an increased use of IO and CGE models in the realm of disaster risk management. A case in point, Rose and Liao (2005), have described how resilience strategies such as inventory management and production recapture can reduce the economic losses in the aftermath of disasters.

---

[1]For example, a search of articles on Web of Science database on September 8, 2020 indicates the disproportionate number of hits of disaster-related articles containing the keyword “infrastructure” versus “workforce.” In particular, of the total 91,544 articles generated by Web of Science containing the keyword “disaster,” 6190 articles contained the keyword “infrastructure” while only 317 articles contained the keyword “workforce.”.

Table 10.1 Definition of DIIM variables and parameters

DIIM term	Definition
$\mathbf{q}(t + 1)$ and $\mathbf{q}(t)$	Inoperability vector at time $t + 1$ and t
K	Resilience matrix containing system-specific rates of recovery
A*	Interdependency Matrix derived from IO data
$\mathbf{c}^*(t)$:	Demand disruption vector at time t

Concepts from the reliability domain have also penetrated the field of IO economics. One notable example is the inoperability measure, which has been used to transform the classical IO model. Inoperability can be interpreted as the complement of reliability (or "unreliability), which describes the extent to which a system is not meeting its intended function. For example, an inoperability value of 0.1 implies that a system is only able to perform 90% of its ideal or "business as usual" output, and this can be due to a disruptive event. As such inoperability is a dimensionless quantity, and its values can range between 0 and 1. The ideal case is a value of 0, and the worst case is 1 when the system is considered in a total failure state (Santos and Haimes 2004). The dynamic inoperability IO model (or DIIM) has been developed to assess the impact of time-varying inoperability on interdependent systems due to disruptive events. For the COVID-19 pandemic, an example of a time-varying inoperability is the impact on workforce, which dynamically changes within the recovery horizon. The formulation of the DIIM is presented in Eq. (10.1):

$$\mathbf{q}(t+1) = \mathbf{q}(t) + \mathbf{K}[\mathbf{A}^*\mathbf{q}(t) + \mathbf{c}^*(t) - \mathbf{q}(t)] \tag{10.1}$$

The DIIM has been used in analyzing the impact of disasters on interdependent sectors of the economy. In this paper, our approach is to create an inoperability input vector representing the reduced level of workforce, as with the case of a pandemic. Using IO data, we assess the dependence of each economic sector on its workforce and multiply it with the overall workforce disruption. Health agencies like the CDC publish data sets on the time-varying impact of disease on the population, which typically generate a wave-like function known as the *epi curve*. Given that the workforce dependence ratios of each sector can be extracted from publicly available IO data, applying the *epi curve* pattern over time can eventually generate the workforce inoperability inputs that can be plugged in to the DIIM formulation in Eq. (10.1).

The impact of workforce-debilitating events on various sectors is influenced by a number of factors. Labor intensive sectors are expected to have higher values of workforce dependence ratios, and consequently can be more vulnerable to workforce disruptions (Santos 2020). Furthermore, sectors that can operate remotely or are capable of allowing its workforce to telework can potentially reduce the adverse impact of disasters on their production of output or the provision of its service to the customers (Firpo et al. 2011). Furthermore, Acemoglu and Autor (2011), Rose and

Liao (2005) discussed how workforce resilience strategies can be implemented to reduce the recovery periods and expected losses from disruptive events.

In the next section, we demonstrate how the DIIM can be implemented to assess the losses from a baseline COVID-19 scenario. We also perform a comparative analysis to evaluate the potential benefits of a mitigated scenario relative to the baseline.

10.3 Results and Discussion

The COVID-19 pandemic has profoundly disrupted the global economy. Millions have contracted the disease worldwide and it has severely challenged the capacity of healthcare systems and resources. As of the first week of September 2020, nearly one million people have died (Worldometer 2020). The US leads the statistics of COVID-19 in both number of infections and mortalities.

While SARS-CoV-2, the virus responsible for COVID-19, has been recognized as highly transmissible and deadly, many researchers have asserted that many of the current cases were preventable (Sebenius and Sebenius 2020). Effective nonpharmaceutical interventions (i.e., containment, suppression, and mitigation) would have dramatically slowed down its progression (i.e., “flattened the curve”), which consequently would decrease the burden to healthcare systems. Pueyo (2020) has emphasized the urgency of implementing nonpharmaceutical interventions in the absence of vaccines. Germann et al. (2006) have performed simulations to show how the curve could be significantly flattened with combinations of pharmaceutical and nonpharmaceutical interventions.

In this section, we perform a comparative analysis of the COVID-19 pandemic in the US using two scenarios based on an actual epi curve and a simulated mitigated scenario. As of the writing of this paper, the epi curve data for the US is available from the beginning of the year until the first week of September 2020 (see Fig. 10.2). It can be seen from the plot that the epi curve started around the first week of March 2020, which will be set as $t = 0$ in our case study. The curve plateaued around Day 30 and was seemingly on the path to recovery until it began another upsurge after $t = 90$ (roughly mid-June). This COVID-19 spike was attributed to the Memorial Day festivities and relaxed restrictions. The epi curve peaked around $t = 135$ (mid-July) and started to decline thereafter.

We used the DIIM to simulate the epi curve depicted in Fig. 10.2 to estimate the economic and inoperability losses incurred by various sectors. In addition, we simulated a second scenario that assumes that the US implemented strict mitigation measures around Memorial Day weekend, which would have prevented the upsurge in mid-June. The economic losses from the two scenarios is compared to give insights as to the magnitude of the potential savings that could have been realized if strict mitigation measures had been observed.

Nonpharmaceutical interventions (NPIs) are generally classified into three measures: containment, suppression, and mitigation. Containment is associated

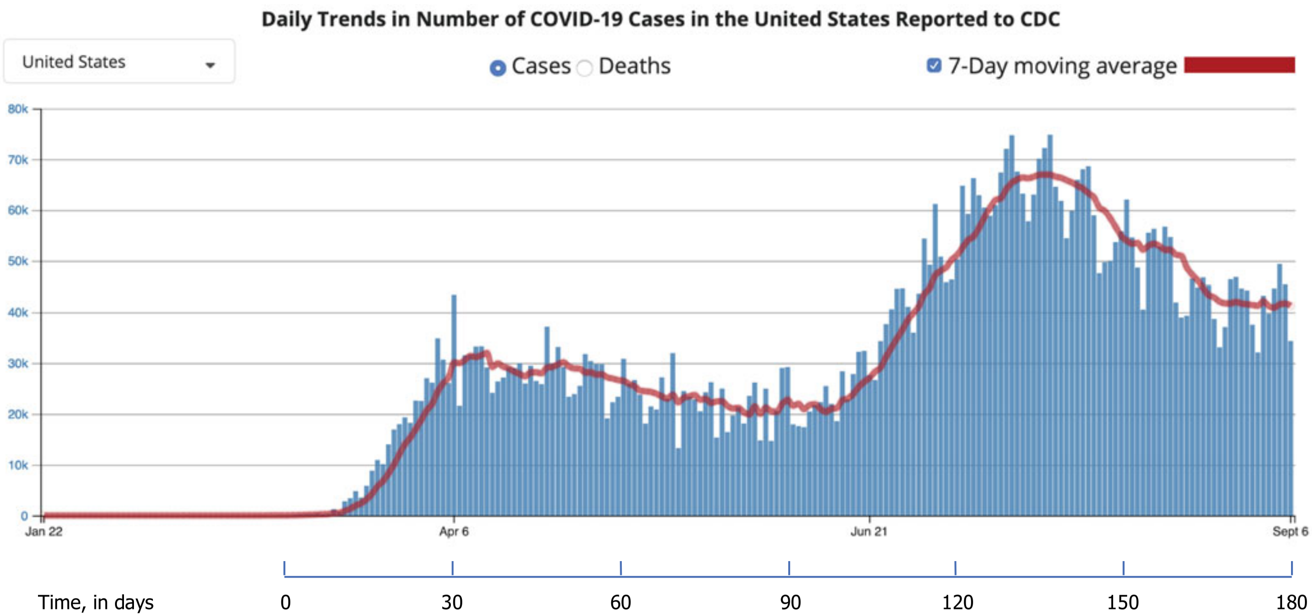

Fig. 10.2 Baseline Epi Curve for the US (Up to date epi curve is available in the CDC website: https://covid.cdc.gov/covid-data-tracker/#trends)

with the process of separating individual cases from the general population and is only effective prior to community transmission or when the pandemic has been effectively suppressed. On the other hand, suppression is the process of lowering R_0 to values lower than 1 (e.g., contact tracing, broad testing, case isolation, travel restrictions, closure of businesses and schools). Finally, mitigation is the process often associated with the “flatten the curve” concept. The 3Ws of mitigation are: (i) wear your face covering; (2) watch your distance; and (iii) wash your hands (Prevent Epidemics 2020). While there has been some public outcry about the imposition of such NPIs, science has overwhelmingly emphasized their urgency and efficacy in flattening the curve (Chu et al. 2020).

We analyze two scenarios in the subsequent case study. The first scenario corresponds to the baseline epi curve shown previously in Fig. 10.2, while the second scenario is a hypothetical case that assumes the epi curve has flattened after the Memorial Day weekend (around $t = 90$). Note that the hypothetical flattening of the curve shown on the right panel of Fig. 10.3 could have been potentially realized by the US knowing that European Union[2] and several other countries were able to mitigate the number of cases for the same timeline.

The two scenarios depicted in Fig. 10.1 describe the epi curves for the *baseline* and *mitigated* scenarios, which are expressed as workforce attack rates. These epi curves are used as inputs to the DIIM formulation shown in Eq. (10.1). The epi curves can be extracted from publicly available data.[3] The x-axis of the epi curve represents time in days, while the y-axis typically gives the number of new infections normalized with respect to 100,000 population, which the literature refers to as the attack rate.[4] The attack rate can also provide information on the extent to which the workforce is rendered inoperable by a pandemic. Each economic sector relies on its workforce to varying degrees (i.e., some sectors are more labor intensive, while sectors that have leveraged automation and IT systems have decreased their dependence on workforce). Hence, the attack rates for the general population can be adjusted accordingly based on sector-specific workforce dependence ratios.

The IO data used in subsequent DIIM analysis was based on the US Bureau of Economic Analysis (BEA), which comprises 71 sectors.[5] Likewise, the interdependency matrix in the DIIM formulation was based on supply and use tables that can be downloaded from the BEA website. The inoperability values in each time step of the model were derived from the epi curves for the baseline and mitigated scenarios. The DIIM was also used to compute the economic losses incurred in each scenario for the baseline and mitigated scenarios. Hence, four charts were generated

---

[2]See, for example, https://www.statista.com/chart/22102/daily-covid-19-cases-in-the-us-and-the-eu/.

[3]The COVID-19 dashboard from the Johns Hopkins University and Medicine provides data on number of active cases, incidence rates, and number of deaths, among others.

[4]The term “incidence proportion” is the more formal term for “attack rate” according to CDC (2012).

[5]Annual IO data sets are published by the US Bureau of Economic Analysis (2020).

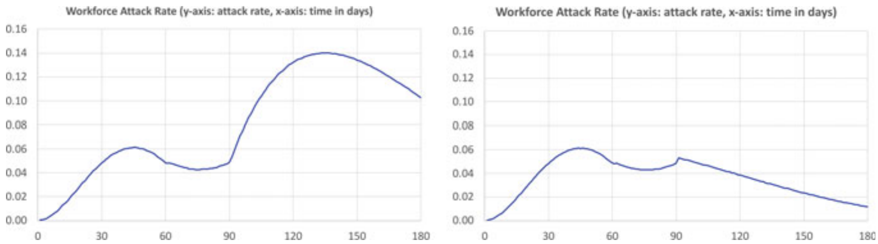

Fig. 10.3 Workforce attack rates for baseline scenario (left) versus mitigated scenario (right)

in this study. Each column of Fig. 10.4 corresponds to the two scenarios (i.e. column 1 for the baseline Scenario and column 2 for the mitigated scenario). Figure 10.4 also has two rows, which represents the two types of results for every scenario (i.e. row A for sector inoperability and row B for economic loss). The subsequent discussions highlight the key results and observations in each of the two scenarios.

Scenario 1: Baseline Scenario

The baseline scenario is based on the actual epi curve for the US, which started in early March 2020 until around the first week of September 2020. The end point was chosen since it was the most recent data when this study was performed. The left panel of Fig. 10.3 depicts the epi curve for the baseline scenario, which shows the plateau between t = 60 and t = 90 and thereafter an upsurge in cases pursuant to the Memorial Day weekend, peaking around t = 135.

In terms of the inoperability ranking for the baseline scenario, the plot for the top 10 most affected sectors is shown in Fig. 10.4 (panel A1). The sectors are: Federal government enterprises; Computer systems design and related services; State and local general government; Social assistance; Management of companies and enterprises; Nursing and residential care facilities; Educational services; Ambulatory health care services; Forestry, fishing, and related activities; and General merchandise stores. The inoperability ranking indicates the criticality of labor dependent sectors, as well as sectors that are directly involved in the provision of healthcare.

In terms of the economic loss ranking for the baseline scenario, the plot for the top 10 most affected sectors is shown in Fig. 10.4 (panel B1). The sectors are: State and local general government; Miscellaneous professional, scientific, and technical services; Ambulatory health care services; Construction; Wholesale trade; Administrative and support services; Hospitals; Management of companies and enterprises; Other services, except government; and Other retail. These results appear to indicate the prevalence of sectors that contribute significantly to the economy (as indicated by their gross domestic product, GDP). For example, State and local government, Wholesale trade, and Construction are sectors that provide the highest contribution to the US GDP; hence their placement in the rankings is intuitive. The ranking also includes sectors that have high labor dependence albeit

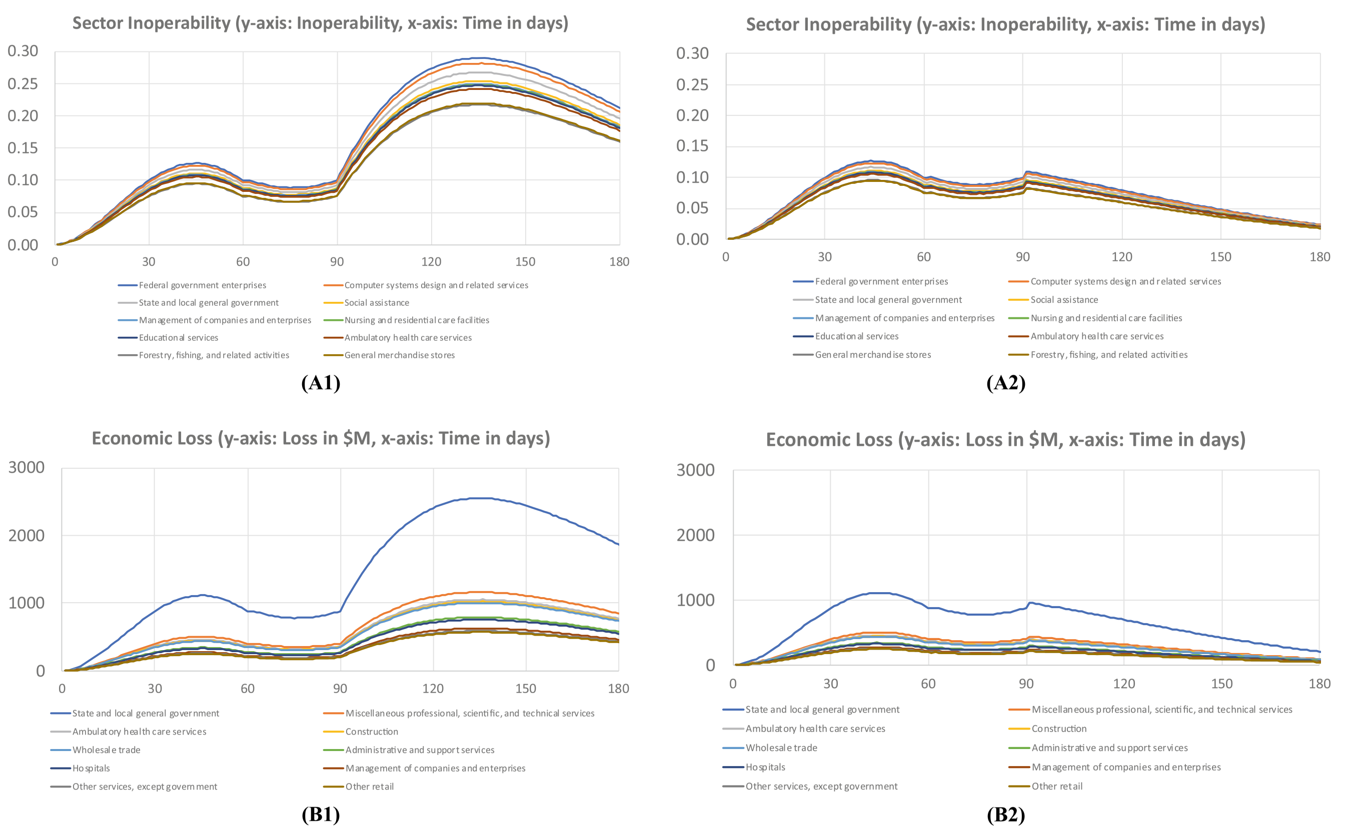

Fig. 10.4 Baseline ccenario: (A1) Sector inoperability, (B1) Economic loss; versus Mitigated scenario: (A2) Sector inoperability, (B2) Economic loss

relatively moderate contribution to the GDP, such as Administrative and support services, Hospitals, Management of companies and enterprises, and Other retail. Though not in Fig. 10.4, it should be noted that the restaurant sector (food and drinking places) landed on the 11th spot of the economic loss ranking.

Scenario 2: Mitigated Scenario

The mitigated scenario is identical to the baseline scenario between the periods $t = 0$ and $t = 90$. The difference lies with the trajectory after $t = 90$, where it is assumed that stricter mitigation measures were implemented around the Memorial Day period and thereafter. This corresponds to the *epi curve* on the right panel of Fig. 10.3, where instead of the spikes in the cases, the mitigated scenario would realize a downward trend assuming stricter measures at the national level were mandated (notably measures pertaining to face coverings and physical distancing, which were lacking in the US). As discussed earlier, such downward trend could have been potentially achieved by the US given that the European Nation and several other developed countries were able to do so for the same time period.

In terms of the inoperability ranking for the baseline scenario, the plot for the top 10 most affected sectors is shown in Fig. 10.4 (panel A2). The sectors are: Federal government enterprises; Computer systems design and related services; State and local general government; Social assistance; Management of companies and enterprises; Nursing and residential care facilities; Educational services; Ambulatory health care services; General merchandise stores; and Forestry, fishing, and related activities. These sectors are similar to those generated in the baseline scenario because of the linearity of the model. It is also worth noting that the results for the inoperability rankings in the mitigated scenario are dominated by labor dependent sectors, as well as healthcare-related sectors.

In terms of the economic loss ranking for the mitigated scenario, the plot for the top 10 most affected sectors is shown in Fig. 10.4 (panel B2). The sectors are: State and local general government; Miscellaneous professional, scientific, and technical services; Ambulatory health care services; Construction; Wholesale trade; Administrative and support services; Hospitals; Management of companies and enterprises; Other services, except government; and Other retail. Many of the sectors in the economic loss rankings for the mitigated scenario are those that contribute significantly to the nation's GDP. This observation is consistent with the results of the baseline scenario.

It can be observed that the inoperability and economic loss metrics generated two different sets of sector rankings. Sectors which are included in the inoperability ranking are typically labor dependent sectors. In contrast, sectors which are included in the economic loss rankings are those that contribute significantly to the GDP. The main difference in the baseline and mitigated scenarios is the assumed flattening of the curve after $t = 90$. Assuming that the number of cases was mitigated around that period and followed a downward trend, the economic losses would also decrease. Table 10.2 shows the economic losses estimated from the DIIM for both the baseline and mitigated scenarios. The economic losses computed by the DIIM for the study period are \$2.996 trillion (15.35% of GDP) and \$0.963

trillion (4.93% of GDP) for the baseline and mitigated scenarios, respectively. The difference of $2.003 trillion is quite significant. Note that such loss estimates do not include government relief, costs associated with hospitalizations, as well as the lives that would have been saved in the mitigated scenario.

10.4 Conclusions and Areas for Future Study

The COVID-19 pandemic has significantly changed how the US, and the world in general, operates. It has disrupted many economic sectors, caused unemployment in many service-oriented sectors, and surpassed the limits of healthcare systems—leading to an unprecedented surge in hospitalizations and mortalities. This paper utilized the DIIM to perform an *ex post* analysis of the impact of COVID-19 on the US economy. A baseline scenario was analyzed based on the epi curve of the US spanning the period from early March 2020 until the first week of September 2020. An uptick of cases occurred after the Memorial Day weekend, and many analysts attribute this phenomenon to the lack of nationally enforced directives on mitigation measures such as face coverings and physical distancing. The surge experienced by the US is a stark contrast to the downward trend of cases achieved by the European Union and several developed countries for the same period.

A mitigated scenario was performed by assuming the US has flattened the curve after the Memorial Day weekend, and subsequently the economic loss results were compared with the baseline scenario. Results from the simulation estimated that approximately $2 trillion could have been saved with the implementation of stricter mitigation measures. This estimate excludes the cost of hospitalizations, government relief, and most importantly the costs associated with the astronomical number of deaths that could have been prevented. In this paper, sectors that were ranked in terms of the inoperability and economic loss metrics comprised sectors that contribute highly to the GDP as well as sectors that are directly associated with healthcare provision. It was also observed that sectors with high reliance on labor suffered significantly, including education, retail, trade, restaurants, and other service-oriented sectors.

Although outside the scope of the current paper, several sectors have leveraged the use of online platforms and other creative strategies to lessen the impact on their operations. Stores have increased their online presence and restaurants have expanded their outside seating and delivery options. Most schools in the US have resorted to virtual teaching. It is also worth noting that some business sectors have seen either a stable or increased demand such as web-based conferencing platforms (e.g., Zoom and Webex), video streaming (e.g., Netflix), and traditional online retail (Amazon).

Furthermore, outside the scope of this paper is the impact of COVID-19 on mental health, as well as the disparity of its effects on various socioeconomic groups. Social scientists have shown that isolation could cause mental health issues such as depression and spin off additional problems such as substance use

Table 10.2 Estimates of economic losses for the baseline and mitigated scenarios

Scenario	Description	Economic loss (in million USD)	% of GDP
Baseline	Epi curve is shown on left panel of Fig. 10.3, surge in cases after $t = 90$	2,995,928	15.35
Mitigated	Epi curve is shown on right panel of Fig. 10.3, decline in cases after $t = 90$	962,665	4.93

(Hawkley and Capitanio 2015). Furthermore, the CDC (2021) has recognized and asserted the existence of inequities that affect minorities more pervasively (e.g., wealth gaps, housing, education, and access to health resources, among others). Such inequities lead to a disproportionately higher number in illnesses and deaths amongst minorities, particularly African-Americans and Hispanics/Latinos (Godoy and Wood 2020).

While the adverse effects of nonpharmaceutical interventions such as isolation and impingement of personal liberty should not be discounted, the consequences associated with public disregard, distrust, or political resistance to the efficacy of mitigation measures are deemed to be costlier and more dire. Furthermore, the paper recognizes the significant losses that can emerge from interventions such as business closures, travel restrictions, and stay at home orders. Nonetheless, the economy is expected to come back and recover, but those who succumbed from the virus are gone forever. A case in point, Correia et al. (2020) concluded that cities that implemented tighter mitigation measures during the 1918 "Spanish Flu" pandemic recovered with higher employment growth several years later.

In summary, this paper explored the efficacy of "flattening the curve" in the context of the COVID-19 pandemic through the analysis of its impacts on the workforce and the associated ripple effects across the interdependent sectors of the economy. From an economic standpoint via the implementation of the IO model, it has been estimated that a flattened curve pursuant to the 2020 Memorial Day weekend could have saved the economy at least $2 trillion. In addition, the authors speculate that a more carefully planned timing in the reopening of the economy would have further reduced the impact of business closures on GDP and employment. Other epidemiological, political, and social dimensions of disaster risk management not covered in this paper need to be further investigated to create a more holistic and robust preparedness and resilience planning for the remainder of COVID-19 pandemic. The modeling framework presented in this paper can also be extended to other disasters (natural and human-caused) to capture simultaneous direct impacts on workforce and critical infrastructure systems. The resulting sector impacts in terms of inoperability and economic losses can be used broadly for formulation of disaster risk management policies (e.g., geographic and temporal staging, allocation, and prioritization of limited resources to reduce the magnitude and duration of disasters on the economy).

Disclaimer: This chapter is based, in part, on prior published research in the special issue on "Risk and resilience in the time of the COVID-19 crisis" (Igor Linkov and Benjamin D. Trump, editors) of Springer's Journal *Environment Systems and Decisions, v40(2), 2020*.

References

Acemoglu D, Autor D (2010) Skills, tasks and technologies: implications for employment and earnings. National Bureau of Economic Research, Inc, NBER Working Papers. 4. https://doi.org/10.1016/S0169-7218(11)02410-5

Agency for Healthcare Research and Quality (2019) HCUP Fast stats: healthcare cost and utilization project. www.hcup-us.ahrq.gov/faststats/opioid/opioidusemap.jsp?setting=ED. Accessed 8 Aug 2020

Alexander GC, Stoller KB, Haffajee RL, Saloner B (2020) An epidemic in the midst of a pandemic: opioid use disorder and COVID-19. Annals Intern Med 173(1):57–58

Barclay E, Scott D, Animashaun C (2020) The US doesn't just need to flatten the curve. It needs to "raise the line." Vox. https://www.vox.com/2020/4/7/21201260/coronavirus-usa-chart-mask-shortage-ventilators-flatten-the-curve. Accessed 8 Aug 2020

Centers for Disease Control and Prevention (2007) Interim pre-pandemic planning guidance: community strategy for pandemic influenza mitigation in the United States: early, targeted, layered use of nonpharmaceutical interventions. https://stacks.cdc.gov/view/cdc/11425. Accessed 19 Mar 2021

Centers for Disease Control and Prevention (2012) Principles of Epidemiology in Public Health Practice. https://www.cdc.gov/csels/dsepd/ss1978/lesson3/section2.html. Accessed 29 May 2020

Centers for Disease Control and Prevention (2017) Community mitigation guidelines to prevent pandemic influenza—United States, 2017. https://stacks.cdc.gov/view/cdc/45220. Accessed 19 Mar 2021

Centers for Disease Control and Prevention (2018a). Health Equity Considerations and Racial and Ethnic Minority Groups. https://www.cdc.gov/coronavirus/2019-ncov/community/health-equity/race-ethnicity.html, Accessed 14 Sep 2020

Centers for Disease Control and Prevention (2018b) U.S. Drug Overdose Deaths Continue to Rise; Increase Fueled by Synthetic Opioids. https://www.cdc.gov/media/releases/2018/p0329-drug-overdose-deaths.html. Accessed 8 Aug 2020

Centers for Disease Control and Prevention (2021) Health equity considerations and racial and ethnic minority groups. https://www.cdc.gov/coronavirus/2019-ncov/community/health-equity/race-ethnicity.html. Accessed 19 Mar 2021

Chu DK, Akl EA, Duda S, Solo K, Yaacoub S, Schünemann HJ (2020) Physical distancing, face masks, and eye protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19: a systematic review and meta-analysis. The Lancet 395(10242):1973–1987. https://doi.org/10.1016/S0140-6736(20)31142-9

Considine J, Shaban RZ, Patrick J, Holzhauser K, Aitken P, Clark M, Fielding E, FitzGerald G (2011) Pandemic (H1N1) 2009 influenza in Australia: absenteeism and redeployment of emergency medicine and nursing staff. Emerg Med Australas 23(5):615–623

Correia S, Luck S, Verner E (2020) Pandemics depress the economy, public health interventions do not: evidence from the 1918 Flu. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3561560. Accessed 7 Apr 2020

Council of Economic Advisers (2017) The Underestimated cost of the opioid crisis. Executive Office of the President of the United States, Washington DC, p 14

Diekmann O, Heesterbeek JAP, Metz JAJ (1990) On the definition and the computation of the basic reproduction ratio R_0 in models for infectious diseases in heterogeneous populations. J Math Biol 28:365–382

El Haimar A, Santos JR (2015) A stochastic recovery model of influenza pandemic effects on interdependent workforce systems. Nat Hazards 77(2):987–1011

Elston JWT, Moosa AJ, Moses F, Walker G, Dotta N, Waldman RJ, Wright J (2016) Impact of the Ebola outbreak on health systems and population health in Sierra Leone. J Pub Health 38 (4):673–678

Eubank S, Guclu H, Kumar VA, Marathe MV, Srinivasan A, Toroczkai Z, Wang N (2004) Modelling disease outbreaks in realistic urban social networks. Nature 429(6988):180–184

Ferguson NM, Cummings DA, Fraser C, Cajka JC, Cooley PC, Burke DS (2006) Strategies for mitigating an influenza pandemic. Nature 442(7101):448–452. https://doi.org/10.1038/nature04795

Firpo S, Fortin NM, Lemieux T (2011) Occupational tasks and changes in the wage structure, IZA Discussion Papers 5542, Institute of Labor Economics (IZA)

Florence CS, Zhou C, Luo F (2016) Xu L (2016) The economic burden of prescription opioid overdose, abuse, and dependence in the United States, 2013. Med Care 54(10):901–906

Fraher EP, Pittman P, Frogner BK, Spetz J, Moore J, Beck AJ, Armstrong D, Buerhaus PI (2020) Ensuring and sustaining a pandemic workforce. N EngL J Med 382(23):2181–2183

Garrett AL, Park YS, Redlener IE. Mitigating absenteeism in hospital workers during a pandemic. Columbia Academic Commons. https://doi.org/10.1097/DMP.0b013e3181c12959

Germann TC, Kadau K, Longini IM Jr, Macken CA (2006) Mitigation strategies for pandemic influenza in the United States. Proc Natl Acad Sci U S A 103(15):5935–5940. https://doi.org/10.1073/pnas.0601266103

Godoy M, Wood D (2020) What do coronavirus racial disparities look like state by state? https://www.npr.org/sections/health-shots/2020/05/30/865413079/what-do-coronavirus-racial-disparities-look-like-state-by-state. Accessed 14 Sep 2020

Guerra F, Bolotin S, Lim G, Heffernan J, Deeks SL, Li Y, Crowcroft NS (2017) The basic reproduction number (R0) of measles: a systematic review. Lancet Infect Dis 17(12):e420–e428

Harris D (2020) Important to remember that #Covid-19 epidemic control measures may only delay cases, not prevent. However, this helps limit surge and gives hospitals time to prepare and manage. It's the difference between finding an ICU bed & ventilator or being treated in the parking lot tent. https://twitter.com/drewaharris/status/1233267475036372992 Accessed 7 Apr 2020

Hawkley LC, Capitanio JP (2015) Perceived social isolation, evolutionary fitness and health outcomes: a lifespan approach. Philos Trans R Soc Lond Ser B, Biol Sci 370(1669), 20140114. https://doi.org/10.1098/rstb.2014.0114. Accessed 19 Mar 2021

Huber C, Finelli L, Stevens W (2018) The economic and social burden of the 2014 Ebola outbreak in West Africa. J Infect Dis 218(5):S698–S704

Jones K, Salzman GA (2020) The vaping epidemic in adolescents. Missouri Med 117(1):56

Kassem AM (2020) COVID-19: Mitigation or suppression? Arab J Gastroenterol 21(1):1

Kayı İ, Sakarya S (2020) Policy Analysis of Suppression and mitigation strategies in the management of an outbreak through the example of COVID-19 Pandemic. Infect Dis Clin Microbiol 2(1):30–41

Leontief W (1936) Quantitative input and output relations in the economic system of the United States. Rev Econ Stat 18(3):105–125

London and Milan (2020) Covid-19 is now in 50 countries, and things will get worse. The Economist. https://www.economist.com/briefing/2020/02/29/covid-19-is-now-in-50-countries-and-things-will-get-worse. Accessed 8 Aug 2020

Miller RE, Blair PD (2009) Input-output analysis: foundations and extensions, 2nd edn. Cambridge University Press, NJ

Morantz C (2005) CDC reports on illnesses in hurricane Katrina evacuees and relief workers. Am Family Physician 72(10):2132

Peiris M, Anderson LJ, Osterhaus ADME (eds) (2008) Severe acute respiratory syndrome: a clinical guide (1). Wiley-Blackwell, Chichester, p 285

Prevent Epidemics (2020) 3 W's to reduce the risk of COVID-19. https://preventepidemics.org/covid19/science/insights/3-ws-to-reduce-the-risk-of-covid-19/. Accessed 15 Sep 2020

Pueyo T (2020) Coronavirus: the hammer and the dance, what the next 18 months can look like, if leaders buy us time. https://medium.com/@tomaspueyo/coronavirus-the-hammer-and-the-dance-be9337092b56. Accessed 25 May 2020

Rose S, Liao S (2005) Modeling regional economic resilience to disasters: a computable general equilibrium analysis of water service disruptions. J Regional Sci 45(1):75–112

Sadique MZ, Adams, EJ, Edmunds WJ (2008) Estimating the costs of school closure for mitigating an influenza pandemic. BMC Pub Health 8(1):135

Sanche S, Lin YT, Xu C, Romero-Severson E, Hengartner N, Ker R (2020) High contagiousness and rapid spread of sever acute respiratory syndrome Coronavirus 2. Emerg Infect Dis 26 (7):1470–1477

Santos J (2020) Using input-output analysis to model the impact of pandemic mitigation and suppression measures on the workforce. Sustain Prod Consumption 249–255

Santos J, Yip C, Thekdi S, Pagsuyoin S (2020) Workforce/Population, Economy, Infrastructure, Geography, Hierarchy, and Time (WEIGHT): reflections on the plural dimensions of disaster resilience. Risk Anal 40(1):43–67

Santos JR, Herrera LC, Yu KDS, Pagsuyoin SA, Tan RG (2014) State of the art in risk analysis of workforce criticality influencing disaster preparedness for interdependent systems. Risk Anal 34(6):1056–1068

Santos J, Orsi MJ, Bond EJ (2009) Pandemic recovery analysis using the dynamic inoperability input-output model. Risk Anal 29(12):1743–1758

Santos J, Haimes YY (2004) Modeling the demand reduction input-output inoperability due to terrorism of interconnected infrastructures. Risk Anal 24(6):1437–1451

Schwartz AM, Wilson JM, Boden SD, Moore TJ Jr, Bradbury TL Jr, Fletcher ND (2020) Managing resident workforce and education during the COVID-19 pandemic: evolving strategies and lessons learned. JBJS Open Access 5(2):e0045

Sebenius I, and Sebenius K (2020) How many needless Covid-19 deaths were caused by delays in responding? Most of them. https://www.statnews.com/2020/06/19/faster-response-prevented-most-us-covid-19-deaths/. Accessed 15 Sep 2020

Smith RD (2006) Responding to global infectious disease outbreaks: lessons from SARS on the role of risk perception, communication and management. Soc Sci Med 63(12):3113–3123

Taubenberger JK, Morens DM (2006) 1918 influenza: the mother of all pandemics. Emerg Infect Dis 12(1):15–22

Thanner MH, Links JM, Meltzer MI, Scheulen JJ (2011) Kelen GD (2011) Understanding estimated worker absenteeism rates during an influenza pandemic. Am J Disaster Med 6(2):89–105

Trump BD, Bridges TS, Cegan JC, Cibulsky SM, Greer SL, Jarman H, Lafferty BJ, Surette MA, Linkov I (2020) An analytical perspective on pandemic recovery. Health security

United Nations Industrial Development Organization (2020) Coronavirus: the economic impact. https://www.unido.org/stories/coronavirus-economic-impact-10-july-2020. Accessed 8 Aug 2020

US Bureau of Economic Analysis (2020) Input-output accounts data. https://www.bea.gov/industry/input-output-accounts-data. Accessed 01 Sep 2020

Volkow ND (2020) Collision of the COVID-19 and addiction epidemics. Ann Inter Med 173 (1):61–62

Watson JT, Gayer M, Connolly MA (2007) Epidemics after natural disasters. Emerg Infect Dis 13 (1):1–5

Weiner S (2020) COVID-19 and the opioid crisis: When a pandemic and an epidemic collide. https://www.aamc.org/news-insights/covid-19-and-opioid-crisis-when-pandemic-and-epidemic-collide. Accessed 8 Aug 2020

World Health Organization (2003) Cumulative number of reported probable cases of SARS from 1 Nov 2002 to 11 July 2003. https://www.who.int/csr/sars/country/2003_07_11/en/. Accessed 19 Mar 2021

World Health Organization (2020a) Statement on the meeting of the International Health Regulations (2005) Emergency Committee regarding the outbreak of novel coronavirus (2019-nCoV). https://www.who.int/news-room/detail/23-01-2020-statement-on-the-meeting-of-the-international-health-regulations-(2005)-emergency-committee-regarding-the-outbreak-of-novel-coronavirus-(2019-nCoV). Accessed 8 Aug 2020

World Health Organization (WHO) (2020b) Severe Acute Respiratory Syndrome (SARS): summary of probable SARS cases with onset of illness from 1 November 2002 to 31 July 2003. https://www.who.int/csr/sars/country/table2004_04_21/en/, Accessed 7 Aug 2020

Worldometer (2020) COVID-19 Coronavirus Pandemic. https://www.worldometers.info/coronavirus/. Accessed 14 Sep 2020

Zhao S, Lin Q, Ran J, Musa SS, Yang G, Wang W, Lou Y, Gao D, Yang L, He D, Wang MH (2020) Preliminary estimation of the basic reproduction number of novel coronavirus (2019-nCoV) in China, from 2019 to 2020: a data-driven analysis in the early phase of the outbreak. Inter J Infect Dis 92:214–217

Chapter 11
Repercussions of Monsoon in the Indian Sub-continent During COVID-19

Renjith VishnuRadhan, T. I. Eldho, Ravinder Dhiman, Ankita Misra, P. R. Jayakrishnan, and Zaki Zainudin

Abstract The world is facing an unprecedented time owing to the ongoing COVID-19 pandemic. The research community is racing to find a solution to contain the outbreak, leading to the proposals of many possible routes of the virus transmission and its dynamics. The Indian sub-continent experiences the monsoon season that leads to heavy rainfall and flooding in the region, affecting the urban areas the most. We list out the outcomes of the synergistic interaction between the ongoing pandemic and the monsoon season in the urban areas and megacities. The major risk factors emanating from the interaction are the impacts on seasonal monsoon-related disease transmission, sewerage effluents, and potable water sources. We also discuss some socio-economic aspects regarding the implications of monsoon during the pandemic time, such as transport disruptions and increased pressure on the accessibility to the health care systems. We hope that our observations shall stimulate discussion and detailed investigations regarding the dimensions of monsoon impact. In addition to this, the observations shall aid the policymakers and governance systems in charting out the best fit mitigation and adaptation strategies to tackle the perils of COVID-19 during the monsoon season.

R. VishnuRadhan (✉) · T. I. Eldho
Department of Civil Engineering, Indian Institute of Technology Bombay, Powai, Mumbai, Maharashtra 400076, India
e-mail: renjithvr@iitb.ac.in; renjitvishnu@gmail.com

R. Dhiman
Jamsetji Tata School of Disaster Studies, Tata Institute of Social Sciences, Mumbai, Maharashtra 400088, India

A. Misra
Institute of Oceanography and Environment, Universiti Malaysia Terengganu (UMT), Kuala Nerus, 21030 Terengganu, Malaysia

P. R. Jayakrishnan
College of Climate change and Environmental Science (CCES), Kerala Agricultural University, Vellanikkara, Thrissur, Kerala 680656, India

Z. Zainudin
Independent Water Quality and Modeling Specialist, Klang, Selangor, Malaysia

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_11

Keywords COVID-19 · SARS-CoV-2 · Monsoon · Urban · Indian sub-continent · Water

11.1 Introduction

The coronavirus disease 2019 (COVID-19) (WHO 2020) is a rapidly spreading novel respiratory infection caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (Gorbalenya et al. 2020). Person-to-person transmission is a common route of spreading the infection via direct contact or through droplets spread by coughing or sneezing by an infected individual (Rothan et al. 2020). Various other transmission routes have been proposed since the diagnosis of the virus; including airborne transmission (Morawska and Cao 2020), dual ocular route (Napoli et al. 2020), fecal–oral route (Hindson 2020), eye to nose route (Qing et al. 2020), perinatal transmission (Alzamora et al. 2020), transmission due to environmental factors (Qu et al. 2020) and venereal transmission (Patri et al. 2020).

Countries in the South Asian region were battling the pandemic when the monsoon season commences around early June 2020. The period of June–December, when the Indian sub-continent is under the influence of the monsoon, is divided into two seasons, the southwest (summer) monsoon from June to September and the northeast monsoon from October to December. The Indian subcontinent receives over 75% of the mean annual rainfall during the summer monsoon season (June–September), with July and August being the peak monsoon months (Kumar et al. 2009). The monsoon season incurs extreme seasonal flooding in the South Asian regions, primarily affecting the densely populated urban areas; some recent examples are 2015 Chennai, 2017 Mumbai, 2017 Dhaka, 2018 Kerala, 2018 Lahore, 2019 Kerala, 2020 Bihar, and Hyderabad floods. This chapter discusses the possible implications and effects of monsoon on the ongoing COVID-19 crisis in the monsoon-influenced regions, where urban agglomerations are prominent. We hope that this discussion will instigate further stimulating and detailed investigations regarding the scale of systematic risks posed by the compound effects of natural hazards and the ongoing pandemic.

11.2 Monsoon and COVID-19 Transmission: The Odds-On

The monsoon season is a season of elevated levels of vector-borne and water-borne diseases, such as dengue, malaria, cholera, influenza, hepatitis, typhoid, and gastroenteritis, which are the more common diseases, among others (Khan et al. 2011; Dhara et al. 2013). The rainfall during the period has profound effects on the epidemiology of these diseases. Previous experiences showed that these infectious diseases pose severe problems of various dimensions for the nations in the Indian sub-continent region. The population is at a higher risk of being exposed to multiple viruses, bacteria, and other infections during the monsoon period compared to other seasons. For example, respiratory viral infections were found mainly during the rainy seasons in Asian, African, and South American countries (Shek and Lee 2003). Epidemiological data showed a relationship between influenza virus infection and rainfall (Pica and Bouvier 2012). Furthermore, temperature and humidity are also among the critical controlling factors that impact the spatial–temporal incidence and transmission of several infectious diseases during periods such as the monsoon season (Chowdhury et al. 2018; Sumi et al. 2013).

A recent study (Sobral et al. 2020) observed a positive correlation between precipitation and SARS-CoV-2 transmission, with countries having higher rainfall measurements, showing an increase in disease transmission. However, the comprehensive nature of the virulence factors associated with COVID-19 during a prolonged rainy season remains unknown until today. There is a prevailing strong wind regime during the monsoon season, and recent pieces of evidence show that wind speed is positively correlated with COVID-19 cases in some regions (Bashir et al. 2020; Sahin 2020). While wind speed alone may not explain much of the variance in the confirmed positive case counts, combined with temperature, wind speed, and relative humidity, it could best predict the epidemic situation (Chen et al. 2020). Monsoon season is a period when there are multi-dimensional complexities of meteorological influences in play across the Indian subcontinent, and it will be worth exploring and evaluating the better-fit epidemic scenarios. It is currently unknown whether COVID-19 increases the susceptibility towards other monsoon induced infectious diseases or- vice-versa. Co-infections are potentially lethal in COVID-19 patients and are unexplored (Cox et al. 2020). A recent study from Northern California reported a co-infection between SARS-CoV-2 and other respiratory pathogens and pollutants (Kim et al. 2020). Co-infections could happen when there is a surge in various diseases during the monsoon period. Co-infections of malaria and dengue in pregnant women with COVID-19 were detected in Mumbai megacity (Maharashtra state, India) during the recent monsoon of 2020 (Mahajan et al. 2020). A recent report (IDSP 2020) has shown that there have been $\sim$44 deaths, which can be under-reported, in Maharashtra state resulting from instances of Covid co-infection with monsoon diseases. Mumbai (Fig. 11.1) was among the first in the state to report these co-infection cases, which is expected due to its heavily urbanized nature. The comparative mortality rate for Covid coinfection in the state was as follows: Covid-malaria > Covid-dengue > Covid-leptospirosis > Covid-typhoid. The dynamics of co-infection during the recent monsoon season in Mumbai can act as a yardstick in managing the challenge more effectively in days to come. Nevertheless, detailed studies in this direction are still lacking; we now know which monsoon infection will render a Covid patient more susceptible to health complications and mortality. Additionally, studies should focus on low-socioeconomic status (SES) households regarding the co-infection scenario as they are one of the most vulnerable sections of the society

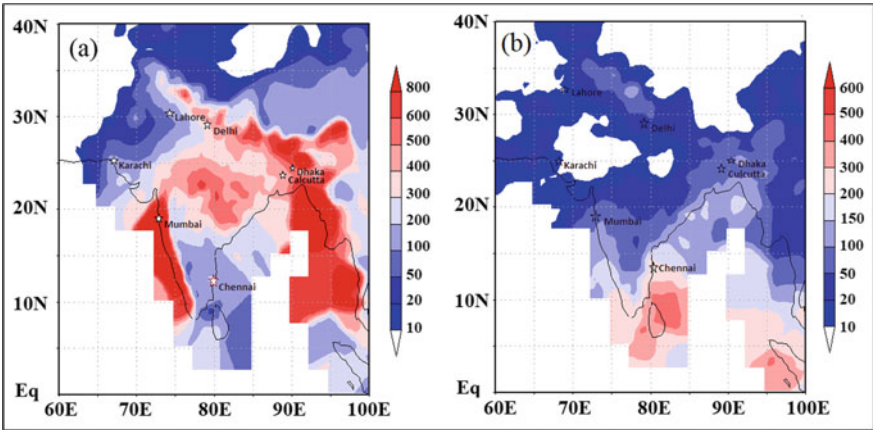

Fig. 11.1 General representation of monsoon rainfall and major cities in the Indian sub-continent coming under the monsoon influence, **a** accumulated rainfall (mm) for June- September (southwest monsoon) and **b** Accumulated rainfall (mm) for October-December (northeast monsoon). *Data source* https://apdrc.soest.hawaii.edu/las/v6/constrain?var=1776; CPC interpolated monthly rainfall

in heavily urbanized South Asian regions, in terms of numbers and vulnerability towards risks in the event of a natural calamity or an epidemic.

Monsoon period is known for the voracious seasonal flooding, causing the flood impacts that are much exacerbated in the urban agglomerations due to various socio-economic factors (Dhiman et al. 2019). Bangladesh, India, and Pakistan are three vulnerable countries in the Indian sub-continent region due to their high population. They are also sites of major megacities and the highest number of positive COVID-19 cases in the sub-continent. Figure 11.1 shows the monsoon rainfall and major cities in the Indian sub-continent. Megacities across this region (Bengaluru, Chennai, Delhi, Dhaka, Karachi, Kolkata, Lahore, and Mumbai) experience severe seasonal monsoon flooding and are the epicenters of disease transmission. These urban agglomerations have insufficient sewage and drainage infrastructures, the capacity of which are often overwhelmed during the monsoons.

Further, untreated sewage effluents are the dominant class of pollutants in the urban centers of South Asian regions (Raju 2019). Seasonal flooding often paves the way for contamination of urban water bodies and municipal water sources by the effluents. When narrowing down to the type of contamination in the region during the monsoon induced flooding, fecal contamination is a prominent aspect (Sirajul Islam et al. 2007; Subbaraman et al. 2013; Nabeela et al. 2014), rendering the population susceptible to infectious outbreaks. Figure 11.2 shows the number of confirmed COVID-19 (as of November 2020) cases in the Indian sub-continent countries where the megacities substantially contributed to the confirmed positive cases. A tremendous surge in positive cases can be observed in all three countries after the onset of monsoon in the sub-continent region. Other countries (Bhutan,

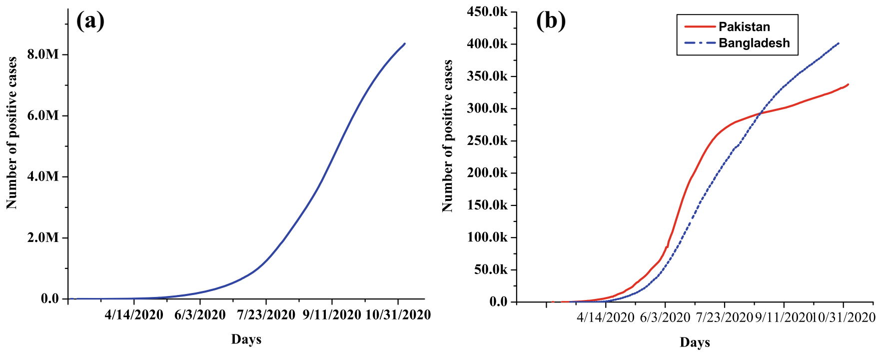

Fig. 11.2 Number of confirmed COVID-19 (as of November) cases **a** India. **b** Pakistan and Bangladesh. *Data sources* India—https://www.mohfw.gov.in/, Pakistan—https://www.nih.org.pk/, Bangladesh—https://www.iedcr.gov.bd/

Maldives, Nepal, and Sri Lanka) in the sub-continent region have relatively less positive cases than these three countries. Research in these directions is yet to commence, as one monsoon season (southwest monsoon) has recently culminated (October 28, 2020) with simultaneous commencement of northeast monsoon rains over extreme south peninsular India (IMD 2020). We have considered Mumbai megacity (Fig. 11.3) as a case where all the factors as mentioned above taper off into a better representation of possibilities during the ongoing pandemic. The two meteorological stations, Colaba (Mumbai city) and Santacruz (Mumbai sub-urban), maintained by India Meteorological Department (IMD), record rainfall data (Fig. 11.4). Table 11.1 shows the highest one-day rainfall and the monthly total rainfall during monsoon months from the two stations, representing the overall rainfall pattern in Mumbai. After June, both the stations recorded a similar pattern of rainfall, as seen in the highest one-day rainfall and monthly total rainfall, indicating widespread rainfall throughout Mumbai. The highest one day July 2020 rainfall occurred on 16th at both the stations; after this, the rainfall became widespread in the region. The number of daily COVID-19 cases (Fig. 11.5) in Mumbai shows a surge after episodes of heavy rainfall, specifically after July. Though there is an observable pattern in the rise in positive cases related to heavy rainfall episodes, the number of daily positive cases also depends on the rate of testing conducted by the local governing body. It should be noted that the monsoon months are a period of various religious festivals in India, which results in close contact between people. This can also be a reason for the surge in daily positive cases. Interestingly, the number of daily cases shows a decreasing trend after the peak monsoon rainfall period in the region. There is a multitude of factors affecting and interacting with the current pandemic in urban areas. The rainfall is one of the prominent factors, as observed in the data. These compounding effects need comprehensive investigations having well-defined objectives, which are still in a revealing stage as the pandemic unfolds various synergistic interactions with various biotic and abiotic factors.

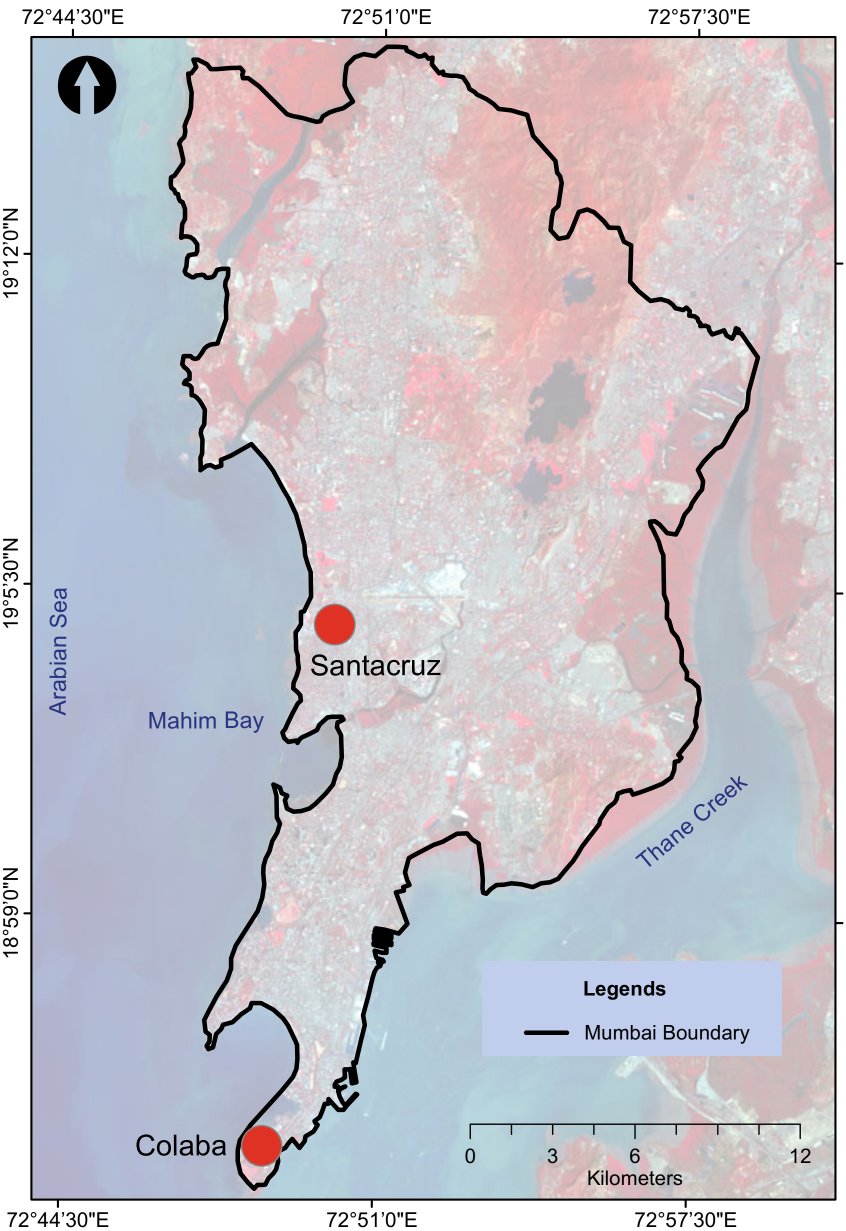

Fig. 11.3 The map of Mumbai marked with Colaba and Santacruz stations

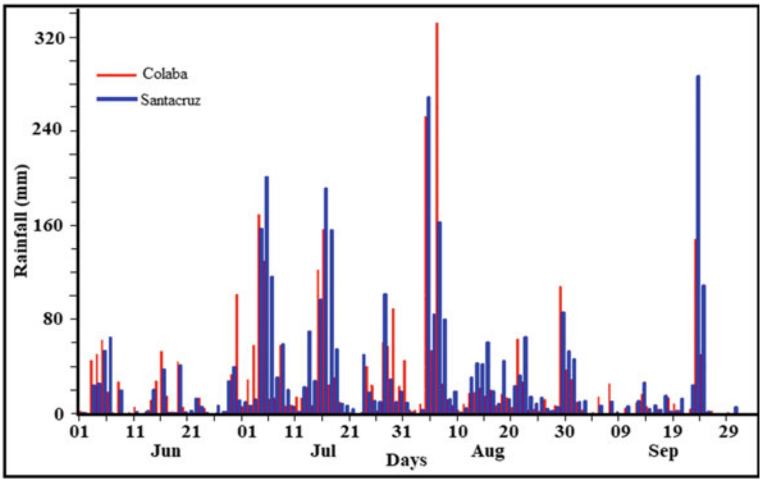

Fig. 11.4 Daily rainfall over Mumbai during the peak monsoon months in 2020 (*Data source* Regional Meteorological Centre Mumbai, India Meteorological Department)

Table 11.1 Highest one day rainfall and monthly rainfall in Mumbai in 2020

Highest one day rainfall (Santacruz)		Highest one day rainfall (Colaba)		Monthly total rainfall (mm)		
Month and day	Rainfall (mm)	Month and day	Rainfall (mm)	Month	Santacruz	Colaba
June 6	64.9	June 30	101	June	395	524.5
July 16	191.2	July 16	156.4	July	1502.6	1229.3
August 4	268.6	August 6	331.8	August	1240.1	1128.3
September 23	286.4	September 23	147.8	September	549.1	320.4

SARS-CoV-2 RNA has been detected in sewage effluents (Ahmed et al. 2020; La Rosa et al. 2020; Randazzo et al. 2020), and there are emerging indications that the viral RNA is present in feces (Wu et al. 2020) and urine (Kashi et al. 2020) of infected individuals. Therefore, considering the lacunae in the functioning of sewerage infrastructure and issues in effluent management in the South Asian cities, it is highly likely that the effluents contain traces of viral RNA. There is a possibility that this can ultimately reach the water bodies and eventually potable water sources. This pathway can be exacerbated during the monsoon flooding. Coronaviruses can remain viable in sewage for up to 14 days, depending on the environmental conditions such as temperature and their association with biofilms (Quilliam et al. 2020) and for more extended periods in the drinking water (Naddeo and Liu 2020). However, their persistence is lower when compared with non-enveloped viruses (Annalaura et al. 2020). There are substantial pieces of evidence of the spread of

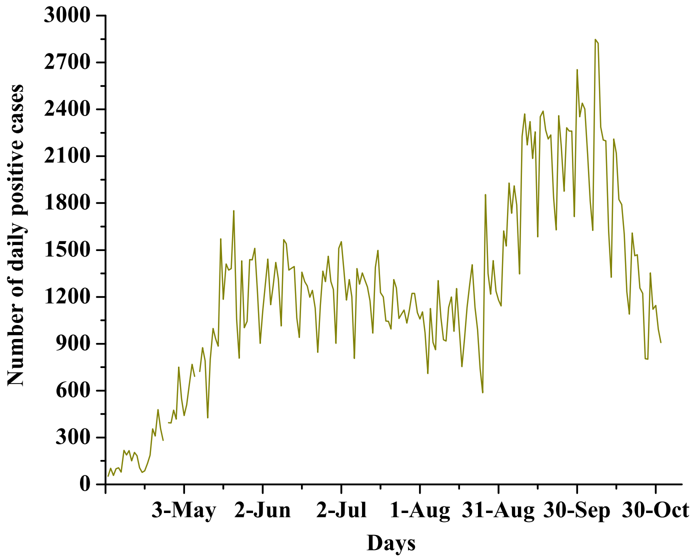

Fig. 11.5 Number of positive cases reported daily in Mumbai (*Data source* Public Health Department—Municipal Corporation Greater Mumbai, Government of Maharashtra)

severe acute respiratory syndrome (SARS), caused by a similar virus as SARS-COV2, in Hong Kong in 2003 by "fecal droplet" route via sewage and drainage systems (WHO 2003). There is a possibility of a fecal transmission route due to the monsoon induced water problems in major cities in the Indian sub-continent. Though the infectivity and the survival of the viral RNA in the effluents are not confirmed explicitly, the infection transmission dynamics during the expected seasonal flooding associated with the monsoon season may pose new risks and challenges. Even if the water-borne route of the COVID-19 infection is not yet established, researchers, policymakers, and governance systems must think ahead and deploy the appropriate pre-emptive investigations to inform countermeasures rapidly (VishnuRadhan et al. 2020).

Personal Protective Equipment (PPE), made of plastics, saves millions of lives during the pandemic (Czigány and Ronkay 2020). Also, single-use plastic materials are widely utilized in the forefront of COVID-19 responses. The management of the disposed of equipment is an immense challenge for cities that are already facing waste management challenges. The quantum of plastic waste generated as a result of the pandemic is massive, especially in megacities. Leakage of large plastic litter (macroplastics) into the ocean is a major environmental problem; a significant fraction of this originates from coastal cities during extreme rainfall events (Axelsson and van Sebille 2017; VishnuRadhan et al. 2019). This is equally true for other water bodies such as ponds, lakes, and rivers. Also, there have been many instances of enhanced flooding due to the clogging of the drainage systems by plastics (Pahl et al. 2017; Lewis et al. 2018) during heavy rainfall. The emerging question in the wake of the COVID-19 pandemic is not whether plastic is a polluter or a protector, but how well plastic usage and disposal can be managed in a sustainable and environmentally friendly way.

11.3 Socio-economic Impacts of Monsoon-COVID-19 Synergy

The monsoon associated flooding usually incurs substantial economic losses and imparts a heavy burden on the local, regional, and national administrative units in the Indian sub-continent. For example, the estimates of the total losses from the July 2005 flood (26–27 July) in Mumbai, range from US$ 1.1 to 5 billion, excluding large informal sectors comprising households and small commercial establishments (Patankar and Patwardhan 2016). Other cities in the sub-continent also experienced similar flood induced economic losses due to the economic–social disorientation and associated shutdown. This can ultimately affect the respective countries' prevailing socio-economic dynamics as these cities are their financial and commercial centers. The monsoon is a major factor influencing the economy of the sub-continent and the global economy. COVID-19 induced economic ripple has started appearing worldwide, and emerging economies are currently affected due to collapsing exports, dwindling remittances, and tightening international credit conditions (Hevia and Neumeyer 2020). The South Asian regions host major emerging economies and global markets, and the combined impact of monsoon flood induced losses, and those by the ongoing pandemic might be overwhelming to the prevailing economic situations.

There are other easily-overlooked threats associated with the monsoon induced flooding. Transport disruptions are widespread in the cities during heavy rains and flooding. These disruptions can potentially impede the accessibility to healthcare facilities by the suspected patients, which can aggravate their health condition. The timing of health care access is a critical factor in managing and successfully surviving the COVID-19 phase. The COVID-19 patients, as well as individuals suspected of having the infection, need continuous interactions with a spectrum of health care facilities, including screening, detection, and post-diagnosis treatments. However, with the restriction of movement imposed by the heavy rains and flooding, access and interaction with the health care system can be nearly impossible. The rapid movement of the essential and medical supplies to the outbreak nodes and quarantine centers in the cities can also get affected. Similar cases were observed recently during the cyclone Nisarga, a rare event during June in the region, which made landfall ~95 km south of Mumbai on June 3, 2020. Though Mumbai was spared from the direct impact of the cyclone, the effects were widely observable. As a precaution, patients under treatment were shifted to safe places by the municipal bodies. There were reports of structural damage to temporary COVID-19 health centers following the cyclone, but the patients were mostly unaffected as they were shifted in advance. The timely decision to shift the patients to more secure locations, and the accurate prediction of the cyclone path have averted a major disaster in the region. This event can be considered as an example of coupled risks and their management during the pandemic, and the resilience of the system towards compounding effects. Currently, we do not know the extent of resilience, in the wake of the pandemic, of health care infrastructure and associated facilities in the South Asian cities to extreme weather conditions such as monsoon flooding and natural hazards such as cyclones. We know one thing for sure, the monsoon season comes with many challenges and opportunities to devise new protocols for tackling modern era natural disasters.

Traditionally vulnerable socio-economic classes in the cities have higher risks of exposure towards various perils of the dynamic interaction between the ongoing pandemic and the monsoon season. This poses multiple justice questions of various dimensions. For example, squatter settlements were the epicenters of the COVID-19 as the disease pattern unfolded in Mumbai. Similar conditions also prevail in other megacities having a substantial squatter population. As the virus continues to spread across the world, it brings multiple new stresses such as physical and psychological health risks, isolation and loneliness, domestic violence, and job losses (Bradbury-Jones and Isham 2020). The monsoon influence can exacerbate these stresses in the densely populated urban areas, increasing the risk factors for the already vulnerable population who are the overlooked victims of the ongoing pandemic. The effective strategies recommended to control the spread of the infection, social distancing, and frequent hand washing are not easy for the millions of people who live in highly dense communities with insecure housing, poor sanitation, and access to clean water (The Lancet 2020). In case of a flood induced by heavy rainfall or a cyclone in densely populated areas, people shall be immediately shifted to relief camps for rehabilitation. There are evident shortcomings in social distancing norms in densely populated areas and can be defied even more without adequate precautions in relief camps. The restricted availability of clean water during these periods can also impede the recommended hand washing regime. However, there is still hope as one of the world's largest squatter settlements, Dharavi in Mumbai, succeeded in containing the spread of COVID-19 that too during the monsoon period when the residents are typically exposed to multiple risks. The first case of COVID-19 was reported on 1st April 2020, where the majority of households rely on community toilets, and physical distancing is impossible. As of November 3, the total active cases in the region dropped below 100, where a single day spike with 94 new cases was reported in May 2020. Rigorous collaboration between the municipality and local low-cost private-health practitioners capped the virus's spread in the Dharavi (Bai et al. 2020). The measures taken by city administration are daily door-to-door screening, unfettered testing, and aggressive hospitalization, isolation in nearby facilities, fever camps, mobile vans were moved around to provide digital X-ray facilities (BMJ 2020). In addition to this, the local municipal body provided free food to a large, contained, out-of-work population at their doorstep. This can serve as an example of resilience in a difficult place during a difficult time. Even in this uncertain time, experience such as those in Dharavi motivates humankind to tackle and manage emerging perils of multi-dimensional nature.

11.4 Conclusions

Monsoons have shaped the history (Gupta et al. 2019) and survival (Gadgil and Kumar 2006) of the inhabitants of the Indian sub-continent. The recent monsoon season during the turbulent times of the COVID-19 pandemic offered various lessons and possibilities in the region to tackle emerging challenges. The potential vulnerabilities of the urban areas and their societies due to the synergistic interaction of the pandemic and the monsoon season expose them to multiple risk factors. It is challenging to isolate the relative contribution of these factors toward the city dynamics during the pandemic time. Still, the urban resilience towards any unforeseen event can be enhanced through proper planning and management, as seen in Dharavi, Mumbai. Governance systems should divert significant attention towards various bottleneck problems during periods similar to monsoon seasons, such as seasonal monsoon-related disease transmission, sewerage infrastructure and effluent management, contamination of potable water sources, and transport disruptions and access to the health care system. Timely interventions of governance systems, and citizens, can reduce the likelihood of exposures to risk factors and prevent mortality to some extent, and thus manage another possible wave of disease outbreak with a much higher coherence and resilience than the present. Potential avenues encompassing multi-faceted ways of the response of urban agglomeration to interactions and repercussions of the COVID-19 outbreak where long rainy season provided opportunities to understand and tackle potential future pandemics as well. An area of possible exploration and utilization is geospatial technologies, which can enhance the efficiency of urban management in the face of the pandemic. We hope that our observations can aid researchers, governance systems, and policymakers in charting out mitigation and adaptation strategies specifically for monsoon-influenced urban areas or similar regions, as the virus is expected to persist (WHO 2020) long time. The concept of living with the flood (Liao 2012) has been successful in many flood-affected regions worldwide. Similarly, the need of the hour is that communities start practicing the concept of living with the virus, at least until developing a vaccine to prevent the transmission of the infectious virus.

Acknowledgements Renjith VishnuRadhan acknowledges an Institute Post-Doctoral fellowship from IIT Bombay. Ravinder Dhiman acknowledges Prof. Janki Andharia, Dean, JTSDS, TISS Mumbai, India, for providing the necessary support. Ankita Misra acknowledges an Institute Post-Doctoral fellowship from the Institute of Oceanography and Environment, Universiti Malaysia Terengganu (UMT).

References

Ahmed W, Angel N, Edson J, Bibby K, Bivins A, O'Brien JW, Choi PM, Kitajima M, Simpson SL, Li J, Tscharke B (2020) First confirmed detection of SARS-CoV-2 in untreated wastewater in Australia: a proof of concept for the wastewater surveillance of COVID-19 in the community. Sci Total Environ 728:138764

Alzamora MC, Paredes T, Caceres D, Webb CM, Valdez LM, La Rosa M (2020) Severe COVID-19 during pregnancy and possible vertical transmission. Am J Perinatol 18:18

Annalaura C, Ileana F, Dasheng L, Marco V (2020) Making waves: Coronavirus detection, presence and persistence in the water environment: state of the art and knowledge needs for public health. Water Res 179:115907

Axelsson C, van Sebille E (2017) Prevention through policy: urban macroplastic leakages to the marine environment during extreme rainfall events. Mar Pollut Bull 124(1):211–227

Bai X, Nagendra H, Shi P, Liu H (2020) Cities: build networks and share plans to emerge stronger from COVID-19. Nature 517–520

Bashir MF, Ma B, Komal B, Bashir MA, Tan D, Bashir M (2020) Correlation between climate indicators and COVID-19 pandemic in New York, USA. Sci Total Environ 728:138835

BMJ (2020) Covid-19 in India: four months into the pandemic—where are we heading? The BMJ Opin 2020

Bradbury-Jones C, Isham L (2020) The pandemic paradox: the consequences of COVID-19 on domestic violence. J Clin Nurs. https://doi.org/10.1111/jocn.15296

Chen B, Liang H, Yuan X, Hu Y, Xu M, Zhao Y, Zhang B, Tian F, Zhu X (2020) Roles of meteorological conditions in COVID-19 transmission on a worldwide scale. medRxiv. https://doi.org/10.1101/2020.03.16.20037168

Chowdhury FR, Ibrahim QSU, Bari MS, Alam MJ, Dunachie SJ, Rodriguez-Morales AJ, Patwary MI (2018) The association between temperature, rainfall and humidity with common climate-sensitive infectious diseases in Bangladesh. PLoS ONE 13(6):e0199579

Cox MJ, Loman N, Bogaert D, O'grady, J. (2020) Co-infections: potentially lethal and unexplored in COVID-19. The Lancet Microbe 1(1):E11

Czigány T, Ronkay F (2020) The coronavirus and plastics. eXPRESS Polymer Lett 14(6):510–511

Dhara VR, Schramm PJ, Luber G (2013) Climate change & infectious diseases in India: implications for health care providers. Indian J Med Res 138(6):847

Dhiman R, VishnuRadhan R, Eldho TI, Inamdar A (2019) Flood risk and adaptation in Indian coastal cities: recent scenarios. Appl Water Sci 9(1):5

Gadgil S, Kumar KR (2006) The Asian monsoon—agriculture and economy. In: The Asian Monsoon. Springer, Berlin, Heidelberg, pp 651–683

Gorbalenya AG, Baker SC, Baric RS (2020) The species severe acute respiratory syndrome-related coronavirus: classifying 2019-nCoV and naming it SARS-CoV-2. Nat Microbiol 5:536–544

Gupta AK, Dutt S, Cheng H, Singh RK (2019) Abrupt changes in Indian summer monsoon strength during the last ~ 900 years and their linkages to socio-economic conditions in the Indian subcontinent. Palaeogeogr Palaeoclimatol Palaeoecol 536:109347

Hevia C, Neumeyer PA (2020) A perfect storm: COVID-19 in emerging economies. VoxEU CEPR Policy Portal. https://voxeu.org/article/perfect-stormcovid-19-emerging-economies. Accessed on 17 May

Hindson J (2020) COVID-19: fecal–oral transmission? Nat Rev Gastroenterol Hepatol 17(5):259–259

IDSP (2020) Integrated Disease Surveillance Programme (IDSP), Maharashtra. https://arogya.maharashtra.gov.in/Site/Form/DiseaseContent.aspx?CategoryDetailsID=Ka8Pzo1mVQE=

IMD (2020) Press release on 28 October, 2020 India Meteorological Department. https://internal.imd.gov.in/press_release/20201028_pr_925.pdf

Kashi AH, Fallah-karkan M, Amini E, Vaezjalali M (2020) The presence of COVID-19 in urine: A systematic review and meta-analysis of the literature. medRxiv. https://doi.org/10.1101/2020.05.15.20094920

Khan MMH, Krämer A, Prüfer-Krämer L (2011) Climate change and infectious diseases in megacities of the Indian subcontinent: a literature review. In: Health in megacities and urban areas. Physica, Heidelberg, pp 135–152

Kim D, Quinn J, Pinsky B, Shah NH, Brown I (2020) Rates of co-infection between SARS-CoV-2 and other respiratory pathogens. The J Am Med Assoc. https://doi.org/10.1001/jama.2020.6266

Kumar MR, Krishnan R, Sankar S, Unnikrishnan AS, Pai DS (2009) Increasing trend of “break-monsoon” conditions over India—role of ocean–atmosphere processes in the Indian Ocean. IEEE Geosci Remote Sens Lett 6(2):332–336

Lancet T (2020) Redefining vulnerability in the era of COVID-19. The Lancet 395:1089

La Rosa G, Iaconelli M, Mancini P, Ferraro GB, Veneri C, Bonadonna L, Lucentini L, Suffredini E (2020) First detection of SARS-CoV-2 in untreated wastewaters in Italy. Sci Total Environ 736:139652

Lewis H, Retamal M, Atherton A (2018) Addressing plastic pollution in India, background paper prepared for Mumbai July 2018 business forum on addressing plastic pollution in India, prepared for Stewart Investors. University of Technology Sydney, Australia, Institute for Sustainable Futures

Liao KH (2012) A theory on urban resilience to floods—a basis for alternative planning practices. Ecol Soc 17(4):48

Mahajan NN, Kesarwani SN, Shinde SS, Nayak A, Modi DN, Mahale SD, Gajbhiye RK (2020) Co-infection of malaria and dengue in pregnant women with SARS-CoV-2. Int J Gynecol Obstet https://doi.org/10.1002/ijgo.13415

Morawska L, Cao J (2020) Airborne transmission of SARS-CoV-2: the world should face the reality. Environ Int 139:105730

Nabeela F, Azizullah A, Bibi R, Uzma S, Murad W, Shakir SK, Ullah W, Qasim M, Häder DP (2014) Microbial contamination of drinking water in Pakistan—a review. Environ Sci Pollut Res 21(24):13929–13942

Naddeo V, Liu H (2020) Editorial perspectives: 2019 novel coronavirus (SARS-CoV-2): what is its fate in urban water cycle and how can the water research community respond? Environ Sci: Water Res Technol 6:1213–1216

Napoli PE, Nioi M, d’Aloja E, Fossarello M (2020) The ocular surface and the Coronavirus disease 2019: does a dual ‘Ocular Route’ exist? J Clin Med 9(5):E1269

Pahl S, Wyles KJ, Thompson RC (2017) Channelling passion for the ocean towards plastic pollution. Nat Human Behav 1(10):697–699

Patankar A, Patwardhan A (2016) Estimating the uninsured losses due to extreme weather events and implications for informal sector vulnerability: a case study of Mumbai, India. Nat Hazards 80(1):285–310

Patrì A, Gallo L, Guarino M, Fabbrocini G (2020) Sexual transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2): a new possible route of infection? J Am Acad Dermatol 82(6):e227

Pica N, Bouvier NM (2012) Environmental factors affecting the transmission of respiratory viruses. Curr Opin Virol 2(1):90–95

Qing H, Li Z, Yang Z, Shi M, Huang Z, Song J, Song Z (2020) The possibility of COVID-19 transmission from eye to nose. Acta Ophthalmol 98(3):e388–e388

Quilliam RS, Weidmann M, Moresco V, Purshouse H, O’Hara Z, Oliver DM (2020) COVID-19: the environmental implications of shedding SARS-CoV-2 in human faeces. Environ Int 140:105790

Qu G, Li X, Hu L, Jiang G (2020) An imperative need for research on the role of environmental factors in transmission of novel coronavirus (COVID-19). Environ Sci Technol 54(7):3730–3732

Raju AS (ed) (2019) Human security in South Asia: concept, environment and development. Taylor & Francis
Randazzo W, Truchado P, Cuevas-Ferrando E, Simón P, Allende A, Sánchez G (2020) SARS-CoV-2 RNA in wastewater anticipated COVID-19 occurrence in a low prevalence area. Water Res 181:115942
Rothan HA, Byrareddy SN (2020) The epidemiology and pathogenesis of coronavirus disease (COVID-19) outbreak. J Autoimmun 109:102433
Şahin M (2020) Impact of weather on COVID-19 pandemic in Turkey. Sci Total Environ 728:138810
Shek LPC, Lee BW (2003) Epidemiology and seasonality of respiratory tract virus infections in the tropics. Paediatr Respir Rev 4(2):105–111
Sirajul Islam M, Brooks A, Kabir MS, Jahid IK, Shafiqul Islam M, Goswami D, Nair GB, Larson C, Yukiko W, Luby S (2007) Faecal contamination of drinking water sources of Dhaka city during the 2004 flood in Bangladesh and use of disinfectants for water treatment. J Appl Microbiol 103(1):80–87
Sobral MFF, Duarte GB, da Penha Sobral AIG, Marinho MLM, de Souza Melo A (2020) Association between climate variables and global transmission oF SARS-CoV-2. Sci Total Environ 729:138997
Subbaraman R, Shitole S, Shitole T, Sawant K, O'brien, J., Bloom, D. E., & Patil-Deshmukh, A. (2013) The social ecology of water in a Mumbai slum: failures in water quality, quantity, and reliability. BMC Public Health 13(1):173
Sumi A, Rajendran K, Ramamurthy T, Krishnan T, Nair GB, Harigane K, Kobayashi N (2013) Effect of temperature, relative humidity and rainfall on rotavirus infections in Kolkata, India . Epidemiol Infect 141(8):1652–1661
VishnuRadhan R, Eldho TI, David TD (2019) Can plastics affect near surface layer ocean processes and climate? Mar Pollut Bull 140:274–280
VishnuRadhan R, Divya David T, Eldho TI, Zaki Z, Casey KC, Jamal HH (2020) Baseline research timing in turbulent times. E-letter comment on 'Research opportunities in pandemic lockdown' in Science 368(6491):594–595. https://science.sciencemag.org/content/368/6491/594/tab-e-letters
WHO (2003) Inadequate plumbing systems likely contributed to SARS transmission. World Health Organization. https://www.who.int/mediacentre/news/releases/2003/pr70/en/
WHO (2020) Naming the coronavirus disease (COVID-19) and the virus that causes it. World Health Organization (WHO). https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance/naming-the-coronavirus-disease-(covid-2019)-and-the-virus-that-causes-it
Wu Y, Guo C, Tang L, Hong Z, Zhou J, Dong X, Yin H, Xiao Q, Tang Y, Qu X, Kuang L (2020) Prolonged presence of SARS-CoV-2 viral RNA in faecal samples. The Lancet Gastroenterol Hepatol 5(5):434–435

Chapter 12
Why Did Risk Communication Fail for the COVID-19 Pandemic, and How Can We Do Better?

José Palma-Oliveira, Benjamin D. Trump, and Igor Linkov

Abstract The SARS-CoV-2 pandemic was an enormous challenge for risk communicators. From the basic life sciences questions regarding the viruses and its effects to the efficacy of associated interventions, communicators around the world had to compete with an endless array of hostile and inaccurate messaging – often within an environment of equally considerable uncertainty and urgency. There were many successes with such public engagement, but considerable opportunities to improve upon. This chapter discusses some of the causes of communication breakdowns, and describes how the corresponding social dilemmas and complexities of socioecological systems can be more effectively characterized and addressed for future crises.

Keywords Risk communication · COVID-19 · Public decision-making · Public health

12.1 Introduction

No matter how robustly engineered or well-intentioned, even the most simple and benign activities are bound to yield some measure of harm. Often, this is due to technical oversight or system design flaws, where material properties of a product possess some unforeseen hazard, or a given activity may yield undesirable consequences to key stakeholders or unintended receptors. In other instances, deliberate or negligent application of a product or activity beyond its intended purpose contributes to unintended downstream risk. Developers and practitioners assigned to

J. Palma-Oliveira
Faculty of Psychology, University of Lisbon, Lisbon, Portugal
e-mail: jpalma-oliveira@psicologia.ulisboa.pt

B. D. Trump · I. Linkov (✉)
US Army Corps of Engineers, Engineer Research and Development Center (ERDC), Vicksburg, USA
e-mail: Igor.Linkov@usace.army.mil

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_12

the oversight of a product or task iteratively adjust the safety requirements and use constraints in order to mitigate or prevent such instances when they occur. At face value, one might assume that the correction of such unintended or undesirable system errors might be corrected by targeted interventions to educate consumers in the general public on safety, in hopes that such discourse would influence a change in public choices and behaviors. At some level, this assumption bears some measure of truth, and is quite often the go-to measure that many authorities utilize when met with disruptions ranging from minor safety violations to major public health crisis.

Unfortunately, this line of thinking also grossly oversimplifies the incentives and framing by which individuals evaluate uncertain information and make decisions. Similarly, such a view fails to account for the impact that risk communication has upon public sentiment and behavior, especially given high-stakes and considerable uncertainty such as with the pandemic. In many cases, global strategy in the earliest days of SARS-CoV-2 followed similar logic, sticking closely to available scientific fact yet simultaneously failing to address budding concerns held by different publics the world over. As a result, considerable public discourse persisted regarding basic principles of SARS-CoV-2 throughout the pandemic's progression, ranging from discussion regarding the types of activities that exacerbate potential for viral exposure to even whether broader policy strategy to 'flatten the curve' should be abandoned in favor of fewer restrictions and broader herd immunity.

One of the most troublesome challenges facing many scientific fields is that, despite elegant and visionary theoretical scientific formulation, comparatively little is understood about how such science is applied and implemented within daily life. For instance, there is a worldwide approved platform and methodology for responding to pandemic outbreaks (methodologies from the World Health Organization to various constituent national governments) that is imperfectly followed and often abandoned as unique conditions within a public health crisis emerge. In other situations, effective and informed strategies are deployed to tackle a specific policy challenge that may not fully account for a wide range of indirect consequences as well as various subjective drivers from individual and community behavior, to economic activity, to various other outcomes. No person or organization is omniscient, and of course some level of uncertainty or unintended consequences must be accepted over the course of a decision-making process, yet a lack of reflexivity and interdisciplinarity may often generate public interventions that have limited success due to unanticipated consequences. In the worst cases, the metaphorical medicine provided by an intervention may be perceived as worse than the initial societal or public health ill that the intervention was intended to cure.

For unique and disruptive fence such as a new pandemic, scientists and policymakers have the near impossible job of (a) quickly researching core scientific uncertainties with respect to hazard characterization, dose response, exposure pathways, and associated health and societal consequences of the contagion, and (b) translating such incomplete and in progress science into clear communication that can be easily understood by the lay public. For the latter point, risk communication for SARS-CoV-2 was exacerbated by a continuous and accelerating level of discourse within popular in social media that facilitated the spread of misleading or inaccurate scientific guidance, particularly given, both, the natural disagreement between the scientists when have to deduct practical rules, and the mediation of the different levels of policy concern. This sowed distrust by skeptical viewers who were concerned not only with preserving their own health, but also mitigating the social, economic, and financial consequences associated with a sudden and sweeping disruption to consumer behavior and overall daily life. Though some nations had greater levels of success than others in gaining the trust of their publics and aligning social activity in a manner that helped reduce the spread of SARS-CoV-2 and reduced the burden of response upon public health systems and emergency responders, overall global communication remained disjointed and largely non responsive to the concerns of those with little public health knowledge or training.

Assuming that the government, at its different levels, is the core actor operating such policy needs, such compliance can be fostered by force or persuasion. In a democratic society, governments strongly favor persuasion over force, although exigent circumstances can and will continue to justify forceful government response if compliance rates are unacceptably low, or if the outcomes of the nagging social dilemma are particularly grave. Ultimately, however, effective persuasion will yield far cheaper and more lasting consequences than legally supported violent force, making it imperative for governments to improve their risk communication strategies to engender public support.

For the coronavirus pandemic, failures of persuasion have triggered limited but visible efforts by police and various other national security forces to limit or end behavior and activities that are deemed to be significantly contributing to the spread of the pandemic. Though these efforts were temporarily and locally effective at ending specifically identified instances of non-abeyance with national ordinance, they did little to convince the public that national strategies and scientific efforts would not only halt the spread of disease, but also do so in a manner that is meeting the core concerns and best interests of various sectors of the public at large.

From a policy perspective, the goal to eradicate a novel disease fundamentally requires the public to align their behavior in a collective fashion, including the sacrifice of some temporary social or economic activity. For the novel coronavirus, risk communication emphasized the message of ‘flattened the curve’, effectively focusing their persuasion upon the need to preserve the ability of hospitals, alternative care sites, and the broader public health system to continue to treat and serve those infected with the virus. Under such a communication strategy, failing to flatten the curve would lead to the number of infected requiring hospitalization far surpassing the ability of a system to provide care, forcing triage to take effect. Within triage, societies health outcomes would likely be far more grave, and may include instances where individuals with relatively mild illness would not receive care required for them to recover, while others with more serious symptoms would be far more likely to suffer for a longer time, or even perish. The ‘flatten the curve’ strategy was an effective communication campaign that gained particular traction via social media, and help initially convince many within the public to observe social distancing as well as stay-at-home orders.

Despite the relative success related to the public health system, no risk communication messages that followed the flatten the curve campaign had nearly the same effect at aligning public opinion, activity, or trust for the policy decisions that followed the initial outbreak of disease within a nation's borders. Likewise, you even offered any measure of insight about what may immediately follow an effective 'flatten-the-curve' intervention. How long should households remain sheltered in place? What types of activities were acceptable within various stages of lockdown or reopening? What measures should be taken to reduce an individual's exposure to the virus? How can individuals and families socially and economically disrupted by the pandemic continue to provide for their immediate and long-term well-being? Various national and international organizations did provide many scientifically-informed answers to these questions throughout the spring and summer of 2020, yet the effectiveness of such communication remain far less overtime. As time goes by, knowledge of the virus behavior and its consequences and, essentially, the nightmare of negative social-psychological and economic consequences also induced changes in the particular strategies (I.e., resistance to novel lockdowns) that, again, have generated an even higher feeling of public distrust to authorities.

Why did risk communication fail for the 2020 coronavirus pandemic? The answer is as simple as it is frequent for disruptive and existential crises: questions held by many within the public were never sufficiently answered, neither from a scientific perspective, nor within subsequent policy decisions centered upon maximizing the utility of public health. Or, when such messages are actually conferred, they are perceived with skepticism and even revulsion by certain groups. As we move forward, however, a far more illuminating question includes: how might we do better? How can we mitigate or avoid future failures of risk communication, and better meet the needs and concerns of an anxious public spheres and time horizons may not closely align with those of scientists, policymakers, or other senior decision-makers?

To be clear, there is no single strategy or solution to this question. Governments and organizations tasked with pandemic emergency response have done the best that they could, with what little information they had, within an environment of considerable public fear and urgency. Future disruptions will have very different drivers and consequences that engender public response and concern, where even the science of risk analysis (hazard, exposure, and effects assessments) must be constructed and evaluated in real time. What can be gained from the experiences of 2020 is that successful risk communication for such extreme crises and emergencies must include a fusion of engineering, social psychology, public health, economics, and various other disciplines to better meet the needs of the broader public in the midst of and in the aftermath of such crises. In this chapter, we frame this challenge to improve public risk communication through the lens of social dilemmas and socio-ecological systems, also arguing that multidisciplinary scientific theory can help build public trust, acceptance, and even participation within emerging strategies to respond to and recover from all sorts of adverse events.

12.2 Social Dilemmas and Risk Communication

Social dilemmas, or collective action problems, are an umbrella for various situations where groups of individuals or organizations would achieve superior outcomes for all participants through cooperation, yet conflicting interests or incentives discourage joint action. Fields such as social psychology and political philosophy have observed such curious outcomes, and have explained the various mechanisms why one or more participants would fail to cooperate to achieve respectively preferable outcomes for all (Dawes 1980; Ostrom 1990). This includes the parable of 'The Tragedy of the Commons', where individuals following rational incentives to pursue concentrated profits at the expense of the broader collective will eventually lead to lasting harms to the broader societal and environmental system if no measures for collective security are adopted (Hardin 1968).

At their heart, nearly all major policy challenges facing modern society stem from social dilemmas. From basic taxation, to defense preparedness, to even broader response to a global pandemic, aligning public participation with major government programs inevitably requires some minimum measure of compliance with the court terms of a given policy, whether it be through the paying of taxes, serving in a nation's armed forces, or making choices that would reduce the spread of contagious disease.

Naturally, individuals and organizations will eventually lose patience for altruistic or cooperative behavior as personal losses accrue and disruption persists for many months. Even so, such changes in behavior from cooperation to skepticism or even selfishness are fundamentally driven by concerns that core needs within a given policy environment are not being met, nor does the affected actor hold sufficient trust in the government or another central authority to sufficiently or equitably address such unmet needs over time. In such instances, it becomes far more important to structure risk communication around the fundamental nature of the social dilemma at hand, with the current case being one where collective action is still needed to reduce the spread of disease through a series of individual and community changes that may have sweeping disruption on daily social and economic life.

Messick and Brewer (1983) argue that social dilemmas are framed as the order and timing of how the benefits and harms of a choice are structured over time. On one hand, there are 'Traps', where guaranteed benefit precedes potential harm. On the other, there are 'Fences', where a guaranteed harm precedes potential benefits. Within both scenarios, critical variables include how delayed the long-term benefits

Table 12.1 Social dilemmas framed as traps and fences for individuals and publics

	Outcome to self	Outcome to others
Trap	*Indulgence (self-destruction)*	*Competitiveness (self-interest)*
Fence	*Investment (self-improvement)*	*Altruism (self-sacrifice)*

or harms might be, as well as whether the agent in question is making decisions as an individual, or on behalf of a broader collective. For either agent, however, incentive structures framed as the timing of benefits and harms within a bounded the rational interpretation of how long-term consequences may arise from a given choice significantly influence the decision-making process well before any government or authority can intervene. This is where risk communication becomes an essential task in order to promote persuasion, yet also it is most likely to fail (Table 12.1).

Such failures are driven by an incomplete understanding regarding how the benefits and harms of choices are framed within different levels of the public. For example, copious research indicates the strong likelihood for tobacco users to experience considerable chronic health conditions in later life, with many risk communication efforts emphasizing such painful and expensive conditions. While this knowledge is crucial to furthering public health science and informing some consumers of such downstream threats, it may have little effect upon certain clusters of consumers less focused upon long-term health (e.g., young smokers in their teenage years), or others with less trust or literacy of broader science in relating to their own lives (e.g., 'smoking hurts some people, but it will not do the same for me'). At the individual level, the 'Trap' of persuading smokers to limit or cease such behavior to prevent potential long-term cancers or other health conditions clashes with the relative guarantee of the short-term chemical rush that smoking provides. In such instances, public health authorities have shifted risk communication to emphasize other and far more immediate harms posed by smoking, including social shaming. Such efforts have experienced some success and have grown popular in the United States, particularly in targeting teenagers and young college students.

Though smoking is a popular example, Traps require further refinement with respect to which actor is forced to absorb the delayed harms. If it is the individual directly experiencing the immediate benefit, that individual's temporary indulgence may be framed as self-destructive behavior if carried out over the longer term. Likewise, if others than the consuming agent are forced to absorb the harms rather than the individual experiencing the benefits, such behaviors may become far more incentivized through competitive action over time, especially if broader society is viewed as having a near unlimited capability to absorb such harms. This latter formulation of Traps comprises a more classic 'Tragedy of the Commons', and are far more difficult to mitigate or prevent if the incentives for competitive individual behavior exceed any suasion or force by central authorities. From a risk communication perspective, communicators must grapple with innate greed, where individual consumers must be addressed in a manner that reduces the perception of delayed harmful consequences and increases in understanding of the likelihood that such consequences will accrue, effectively changing the payoff structure to dis-incentivize the continuance of such behavior over the longer timeframe.

Where Traps include social dilemmas of immediate perceived benefits against potential delayed harms, Fences are the opposite formulation. More specifically, individuals or organizations are required to experience immediate and guaranteed losses in order to unlock the potential for certain gains, whether such gains accrue in the short or long term. One popular Fence includes the purchase of insurance to safeguard longer term welfare, where the immediate loss of money is used to guarantee the potential for longer-term benefits if certain qualifying conditions arise (e.g., medical insurance for surgery or expensive treatment, house insurance against a fire, disability insurance against future lost wages from an accident, etc.). Certain forms of insurance are viewed to have a strong likelihood of paying out over time, such as with medical insurance in the United States. Even then, however, many healthy individuals have viewed expensive health insurance programs and services that they may likely not need in the near future, particularly at a younger age.

To better understand social dilemmas driven by Fences, it is important to understand the dynamic of how harm and benefit are realized. For example, in cases where the individual would directly yet only potentially benefit from their immediate losses were harms, such behavior may be understood as investment, and corresponding risk communication framed as furthering self-improvement. Likewise, if other individuals or broader society are two potentially benefit from an individual's immediate losses, such behavior may be understood as altruistic, with risk communication needing to emphasize how the individual may still acquire some degree of benefit by participating within broader collective action. One example of this includes vaccination campaigns, which from a public health perspective are intended to gradually eradicate the spread of virulent disease through mass inoculation. Despite the immediate unpleasantness of vaccination as well as possible side effects, individuals still do benefit from decreased likelihood of becoming ill from a given disease, and are less likely to become disrupted socially or economically over the long-term if a disease outbreak is to occur. Unlike with Traps, where risk communicators are forced to contend with innate human greed, risk communication for Fences must address concerns of efficacy and fairness. More explicitly, individuals or organizations can be persuaded to take immediate but acceptable losses for the potential for some long-term concentrated or distributed benefit if it is demonstrated that such sacrifices are proportionate to potential gains, in that other equivalent actors are making similar sacrifices along a similar magnitude.

The SARS-CoV-2 pandemic can be globally formulated as a "Fence". At the pandemic's onset, individuals and households were asked to curtail many vital and meaningful functions of daily life to better achieve social distancing, with an understanding that such sacrifices may prevent the individual from becoming ill with the novel virus and will also, in the aggregate, prevent local public health systems from becoming overwhelmed beyond their operating constraints. Initial compliance with such measures was generally successful, yet as time wore on, many began to question whether their personal sacrifices were producing any necessary tangible benefit, or whether disruptions posed by the reduction of socioeconomic activity were antithetical to their personal incentives and payoff structures. As a result, many polities had difficulty maintaining and aligned platform of social response to the pandemic, given that continued individual and household sacrifices produce significant and potentially lasting negative consequences while benefits to the public health system became viewed by many as less urgent or even necessary. As a result, social distancing policies gradually degraded in their effectiveness over time, with few risk communication efforts accurately targeting the concerns held by various groups most likely to ignore government policy needs.

Using the social dilemmas language of, pandemic risk communication efforts require recurring impositions or even harms to the individual (e.g., social distancing, lack of participation in public life, masking, etc.), in order to potentially preserve a public health system over an indeterminate period of time. Importantly, the hazard of the novel coronavirus to a given individual without certain risk factors is uncertain and not likely fatal, making it deceptively tempting to disregard social distancing requirements if no exponential search in cases is present (notably, such lines of thinking generally ignore the uncertain and often quite debilitating long-term consequences experienced by many recovering from COVID-19).

12.3 Social Dilemmas, Incentive Structures, and the Novel Coronavirus: Aligning Intervention Needs with Effect Communication Narratives

To make matters more complex, the present is a continuous, permanent, and contextually-driven, choice between positive -and utterly much more automatic- and negative framed behaviors. In order to see the negative behaviors as more probable, either from an individual or from her or his group perspective, the social agent has to perceive a specific balance between the negative or positive uncertain consequences in the future. This is relatively easy at the onset of a pandemic, when fear and excitement of a new threat drives attention and response, and when policy interventions to halt or eliminate the pandemic are perceived to be relatively short-lived, with any losses or harms to affected individuals being repaid by authorities later on. However, as the pandemic drags on, individual and household sacrifices become magnified and grating (e.g., unemployment, high costs of health care, disrupted education, etc.), especially when doubt exist among certain groups that authorities will avail disrupted or harmed individuals.

To fully grasp those differences let compare diverging groups: adolescents, and seniors (70+). By February 2020, some evidence was available to suggest that, controlling for certain factors such as poverty and general ability to seek quality healthcare, adolescents had very low probabilities of severe complications or death, while those of advanced age were probabilistically more likely (importantly, no information on potential long-term effects was available at this time). R Given such information, it would be sensible and unsurprising if those of higher risk groups such as the elderly were to carefully control their potential exposure to the pandemic in its earliest days, when considerable uncertainty abounds regarding how prevalent the virus may be due to asymptomatic transmission amongst much of the population. What is unclear is how internalized incentive structures and reference frames within these populations might change over time, and as more information about the prevalence of spread of the pandemic comes available (e.g., relatively high numbers of active cases within a dense urban area, versus relatively low cases or even no underlying community spread within remote or rural areas).

To address this question, our team conducted a series of interviews with 40 Portuguese individuals (above the age of 70), randomly distributed across the country in dense urban as well as less populated suburban and rural environments. Participants were screened for their basic knowledge and understanding of the pandemic and its associated risks, including how this virus is spread, how to prevent transmission, how contagious it is, what its main symptoms are and who is at most risk. The participants' beliefs and behaviors in the early and later stages (February to August) perceptions of the pandemic were comparatively evaluated. Curiously, despite considerably less SARS-CoV-2 transmission in Portugal's rural hinterlands, the elderly participants in these regions still maintained social distancing and other lockdown measures in a manner consistent with elderly individuals in Lisbon and other population centers, where viral transmission is far more

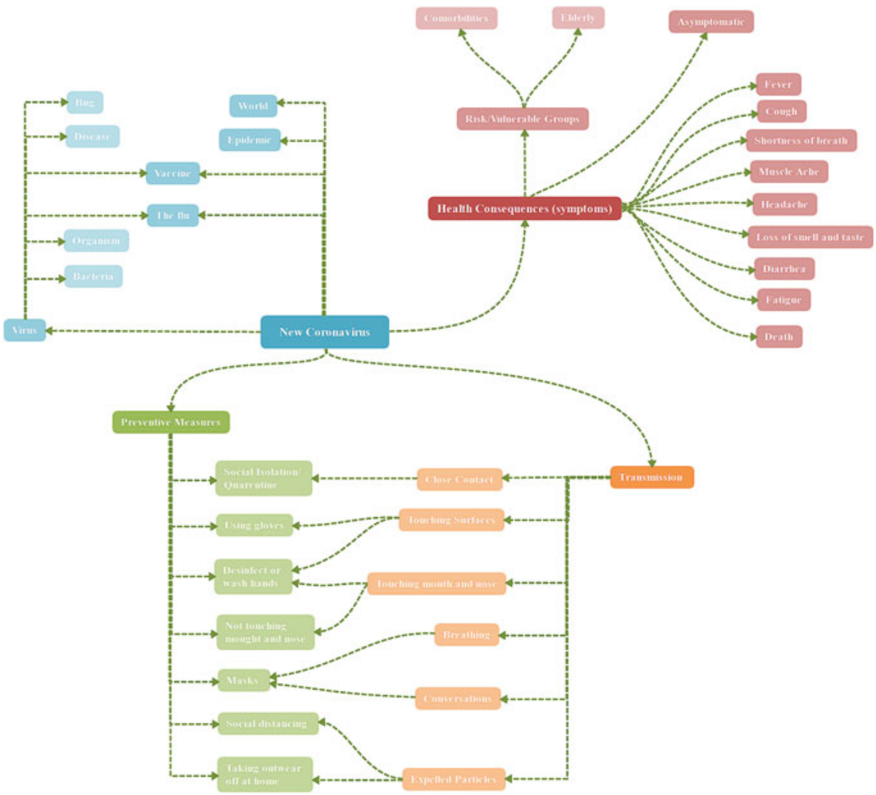

Fig. 12.1 Mental map of the SARS-COV2 and the Covid-19 disease. The strength of the lines correspond to the frequency of the connections

elevated (Ricoca-Peixoto et al. 2020). In essence, despite low levels of exposure within areas of limited community spread, the cognitive anchor of probabilistically greater opportunities for hospitalization and death incentivized such elderly individuals and households to adhere to government lockdown policy, and overcome the "Fence" associated with social distancing. In Fig. 12.1, a common mental map of participants is constructed, which was little changed over the course of the first wave of the pandemic in Portugal.

Turning to an adolescent cohort, the analysis is completely different. Assuming that the individual has no underlying risk factors (e.g., diabetes, heart disease, cancer, or other immune-compromising conditions), the Fences mandated by government policy became viewed as an overwhelmingly net negative that had few direct benefits to one of young age and good health. Instead, after the initial severity of the outbreak subsided, the incentive structures and mental models of such individuals shifted towards justifying behaviors contrary to government mandate. Reports from various countries indicate that such a shift towards adolescent behaviors that exacerbate the spread of the epidemic was continuously observed in urban areas as well as rural areas regardless of the severity of underlying outbreaks.

The impact of the uncertain negative consequences are much smaller conducting to a smaller risk perception. In this case the weight that a younger social agent, from a perspective of limited rationality, assigns judgment that favors *guaranteed* social benefits while dismissing the *low possibility* of downstream harms—ignoring the potential to spread the disease to more vulnerable populations. In essence, top-down risk communication efforts to younger people centered around the preservation of public health increasingly fell upon deaf ears regardless of location, with such younger individuals finding little direct benefit to comply and considerable harms if they did so. There is a tendency within both popular and scholarly literature to attribute the risk-seeking behavior (for instance, attendance at parties and public gatherings) to the character deficits of those social agents (but see Rowell and Connelly 2012; Silvers 2012). However, from the reference point of the younger individual, such behaviors are far from irrational or self-defeating, but instead a clear attempt to overcome a perceived social dilemma whereby broader society would inflict guaranteed lost opportunities (e.g., socialization, income, etc.), in favor of protecting against population health threats that have little to do with the health or well-being of the specific agent.

What makes SARS-CoV-2 so challenging from risk communication perspective is that public health stakeholders and policymakers are grappling with Traps and Fences near-simultaneously. On one hand, public health authorities are attempting to convince broader publics to forgo comfortable, enjoyable, or financially necessary socioeconomic activities that would otherwise exacerbate epidemic spread and increase the challenge of contact tracing. Similarly, public health authorities are grappling with rising concerns and reluctance of publics to consume certain treatments or an eventual vaccine, where anti-vaccination beliefs or mentalities are rising in popularity around many portions of the globe, and even those with some scientific and public health literacy growing concerned that the SARS-CoV-2 vaccine may have unacceptable side effects or be of limited utility.

These and other social dilemmas have formed around considerable scientific uncertainty as well as interrelated systemic crises and socioeconomic suffering. Government lockdowns as well as voluntary reductions in social activity in consumer spending has dramatically reduced the income of many millions around the world, dramatically increasing global poverty and leaving many millions more unemployed and at risk of long-term or even permanent reductions in wealth, happiness, health, and broader life trajectory. Similarly, many within the public have unresolved questions about the core science of SARS-CoV-2 response, driven by flagging trust in government or science authorities. For example, are masks useful to prevent infection, and are they safe for long-term use in the workplace and beyond? How easily does the disease spread? Which groups, be they racial, ethnic, socioeconomic, age-based, or various others are more at risk of more severe outcomes requiring hospitalization, and why? If social distancing and lockdown measures are to continue, what policies or practices will protect those affected by losses of income or freedom from long-term or even permanent disruption?

Scientifically and institutionally, policymakers have many clear answers to these questions, yet their message may not be adequately framed to address the social dilemmas at hand, or they may not sufficiently address the related yet unique concerns that individuals and communities may have that do not appear to be widely discussed or resolved within senior levels of government or amongst trusted decision-makers. A currently overlooked question is that not only scientists and technologists can also have a specific value function that are based in values as, more importantly, the value implicit function of the policy makers are based in their own social dilemma that hardly meet all social concerns of all people at all times. In the next section, we discuss how other important systemic and social-psychological-economic factors can help to further understand this complex dynamic.

12.4 A Social-Ecological Perspective

The broader social fabric is comprised of various interwoven social-ecological systems—some of which are mutually reinforcing, while others are naturally positioned to be at loggerheads (Walker et al. 2004). Such subsystems are relatively obvious and long-standing within literature, such as economic and financial status, social capital, family and community interconnectedness, and various other shared identities. However, other critical determining factors include the position of an individual or household within a given infrastructural and environmental context, including the relationship with and utility derived from their surrounding settings. Each component carries with it a variety of sociopolitical expectations and underlying belief systems that both influence behavior as well as frame risk-based incentives and perceptions that, in turn, drive the relative effectiveness of a risk communication upon the individual. Driven by interconnectedness, relatively small perturbations within a microenvironment can trigger localized yet substantial shifts in the behavior or activity of a targeted individual or group, such as encouraging objectively risk seeking behavior or self-preservation, respectively.

Such shifting and adaptive environments are described in literature as 'complex adaptive systems', where information from the surrounding environment informs the perception of risk and opportunity on a constant and even overwhelming basis (Florin et al. 2018). As human cognition is incapable of absorbing an understanding massive quantities of information as well as weak signals regarding potential threats (e.g., within a 'panarchic' environment as described in Allen et al. 2014), belief systems and identities provide a series of heuristics and decision frameworks that drive the perception and internalized analysis of risk. Though such individuals and groups are capable of shifting or adapting their frames, it is more common that disruption or stress will be viewed via a confirmatory bias framework whereby signals will be derived that activate core assumptions or group identity beliefs to guide decision-making. In this way, the belief systems within such core identities and group subsystems utilize uncertainty and risk as something of a Rorschach test, and selectively absorb and act upon pieces of information consistent with prior held views. In this way, social-ecological identity within broader systemic stress such as a pandemic is highly resilient to disruption, and is quickly able to recover and adapt to the transforming nature of a new environment unless an overwhelming shock or stress is absorbed that fundamentally changes the nature of risk-reward payoffs and social expectations (Hynes et al. 2020; Palma-Oliveira and Trump 2016, 2018).

So, how might policymakers and societal leaders utilize these different and even occasionally competing frames and incentives to align public activity and behavior with broader societal need to reduce the harms and disruption of a pandemic, when risks to health are concentrated within specific groups, while forgone socioeconomic opportunities are generally (but not always) concentrated in others? More succinctly, how can risk communicators overcome social dilemmas? Though there is no universal answer, and absolutely necessary first step includes understanding the timing and trade-offs within risk reward structures of an agent's incentives, and craft messages and interventions that better target an instant socially optimal behavior. Such a task is far from easy, and is exacerbated by underlining social inequalities and perceived inequity in the concentration of lost opportunity by certain groups in order to preserve the health and well-being of others. Such notions are further described in the below section.

12.5 Social-Psychological Dimensions of Social Ecological Systems

Fundamentally, social dilemmas arise when perceived differences between an agent and a collective foster diverging behaviors, beliefs, and expectations within a given population. For those with homogenous incentives, acting against the best interest of the group is heavily disincentivized, and can result in significant losses to the agent on behalf of the group. Likewise, for those societies with sub-populations that possess clashing incentives, losses to the ‘other’ are not necessarily seen or felt as something that is fundamentally harmful, or even to be avoided, if the outcome of such an action is a direct benefit to the agent’s household or direct social circle. Such differences are magnified in existential or sweeping crises such as a pandemic, when clashing incentives and even intergroup mistrust or disrespect make it difficult to generate an alignment of actions and outcomes.

Within socio-ecological systems, independently of their complexity, one can encounters groups that seem themselves as minority or a majority in terms of power relations. Social psychological literature have shown that the way those groups see themselves and perceive the information provided to them is severely different. Minorities tend to be consistent and provide their members with an optimal distinctiveness feeling—something that balances the two basic driving forces that a given social agent search in group belonging. Brewer (1991) identifies two such drivers, including (a) the need for assimilation within a larger group of individuals that could confirms one values, and (b) the need for differentiation that confirms that our group is sufficiently different from other groups to provide a distinct identity. A majority usually is more unbalanced in these two factors than a minority, and is less likely to suffer serious or lasting and localized harmful consequences if such drivers are unmet over time. The consequence is that a small yet aligned and cohesive group can provide its members a higher satisfaction than a larger, more amorphous, and less aligned majority.

The importance of the social groups and the definition of the different geographic contexts are shown in the research that concludes that neighborhoods. For instance, show different social identities (Benardo and Palma-Oliveira 2016a, b) that have consequences in the way people acquire or adopt certain types of behavior and discriminate the other groups. Individuals tend to evaluate their own domicile and community as less polluted/hazardous, and is viewed as an object of a lower risk perception than adjoining or distant places, even if evidence to the contrary may be readily apparent. This tendency to differentiate their own particular community with different risk perception can be a factor that could interact positively or negatively with the target protective behaviors accordingly the context defined by the specific social-ecological systems.

The COVID-19 pandemic does not exists in a vacuum. There is a set of constrains that are dependent of the way each social-ecological system is organized and the different groups ideological frameworks where developed. When an information about a pandemic spread is issued it is assimilated in accordance with the particular belief system of the different groups. Of crucial importance is the way how leadership recognised by the group reacts and supports the message. The information does not hit a certain blank space that was void. By the contrary, people will made sense on that information according to their beliefs system. For instance, imagine a social agent that is prone to conspiracy theories and illiterate to the way science works. In this context one can expect that any kind of inconsistency or change in the communication will be interpreted as a signal that confirms what he or she “knows” in the first place.

Risk communication, as it is implicitly framed, is a kind of informational influence where the cognitive and rational component is stressed. Unfortunately there is no way of seeing a valid information independently of the social context. The very same information that persuades one group will launch a negative reaction from other group. As Turner (2005) puts it "one group's expert is another's crank". Thus, how one can evaluate the expertise if one is not an expert? The expertise is valid because we define the expert as an expert. And we define someone as an expert if belongs to our group and/or our belief system is able to accept the expertise as valid. And usually an expert is evaluated as high in competence but low on warmth what normally deeply undermines her or his influence (see Cuddy et al. 2008).

If a social group, particularly when defined within a specific and geographical social-ecological system and/or portrait themselves as a minority, sees the information as a top-down imposition mainly at odds with their belief system and in direct confrontation with their perceived livelihood. Thus, it is predicted that, in that case, the probability of trusting and acting upon the information is low.

Culturally, there are factors that influence how a payoff structure is perceived within and between various pertinent actors. For instance, if we compare individualist cultures from collectivist cultures, we would predict that greater socioeconomic and cultural cooperation would somewhat override individual imperatives and concerns stemming from critical policy initiatives that infringe upon individual or household health and wealth. Likewise, for societies with greater prevailing individualism, payoff structures are slanted towards individual risks and rewards, placing less weight on the needs of a broader collective. Using Vietnam (collective) and the United States (individualist) as test cases for this divide, Parks and Vu (1994) found that broader societal norms anchor the payoff structures in social dilemmas and can, to a certain extent, influence the willingness of individuals to participate within collective action. These contexts will undermine the weights and balances of the social dilemmatic context present in all crisis and pandemic situations by stressing the positive that are lost by the application of the new rules and augments the uncertainty of the negative consequences.

Further, uncertainty is not an objective feature. Uncertainty in a social context, following Turner's (2005) social power theory, which only arises as a social product of disagreement between two social agents that expect to agree. If two people belong to two different social groups with different beliefs and they expect to disagree. There is only the need to solve situational uncertainty when people disagree when they expect to agree. It they expect to disagree there is no uncertainty—at least in how risk messaging is intended to be constructed, understood, and acted upon.

Earlier, we noted that the preferred mechanism of governments to foster social compliance is persuasion. However, how can one agree with someone that one expects, at the forefront, to disagree? Sending a message that can be accepted will demonstrate power. Effective persuasion (based in the acceptance of the statement as valid) is only probable when people shared the same group, ideology, and beliefs. Power can be exerted by persuasion but only given those important caveats. Power then becomes, as Turner (2005) points out, control, that is actually the capability of making people do what one wants when they are not persuaded or are even uninterested in the specific behavior. And, control can acquire the form of authority (based in in-group norms and, in order to be accepted, be recognized as such) or, if that does not work, coercion (attempting to control the behavior of others against their will).

The particular social dilemmatic nature of the situation also can explain the dynamic of seeing a message as a needed information or basically a coercion attempt. Trust, an important factor in risk communication can only be fully understood given this framework. Trust is attributed much more easily to someone from the same group, sharing the same beliefs and understanding the dilemmatic situation.

Palma-Oliveira and colleagues (2018) developed a method that account for those variables to solve the so-called "Not-in-my-Backyard" (NIMBY) problems proposing a two-step procedure that were able to overcome those constraints. However, such conflictual contexts are characterized by the existence of with a certain social ecological system with a specific number or sub-systems. In the context of a pandemic, isolation of a social ecological system is impossible, and one needs to deal to a diverse array of social ecological systems and groups that have cross belongings to different systems at the same time.

The social dilemma framework normally implies that a constant payoff informs the parameters of a given system. However, the reasoning presented in this chapter is that, not only do such payoff structures differ wildly across different social-ecological systems, but also that such incentive structures could be differentiated across diverse social groups and geographies via various subjective anchors (e.g., cognitive, socioeconomic, etc.).

12.6 Risk Communication Complexity in the Pandemic

The beauty of science is that it is underpinned by fundamental tests of cause and effect. The result of such experimentation is to uncover some objective truth, or at least a range of possible and likely outcomes. However, risk communication vastly complicates the implementation of science by injecting substantial subjectivity and normativity into scientific debates—all contributing to complexities in how messages should be crafted to confidently speak to groups of various sizes and incentive structures. In a pandemic one should have, besides the global framework provided by central public health authorities such as the World Health Organization or national Centers for Disease Control, a much more complete understanding and anticipation of human responses to scientific knowledge and its accompanying implementation by an eager and even anxious government. No universal communication strategy will generate a level of compliance and trust at all stages of a pandemic, making it necessary to differentiate the messages and mediums of communication to best meet the needs and incentive structures of various socioeconomic and socio-ecological groups and boundaries. In some instances this may be relatively easy, such as convincing a particularly at risk group of the need to avoid situations where unnecessary exposure to the virus. In others, this may be relatively difficult, such as convincing a group with few to no known risk factors to do the same.

For the latter, clearly articulating messages that speak to the risk-reward payoffs, incentives, and frames is critical for a risk communication strategy to succeed. For such groups, it is not enough to simply communicate knowledge of hazard and exposure, but also how temporary sacrifices by such groups will generate real intangible benefits, and that such sacrifices will be rewarded at various points in time. Such messages should be carefully couched to accurately characterize the Trap or Fence that characterizes the social dilemma at hand, and more effectively incentivize desired behavior through reasonable interventions that align with the beliefs, expectations, and needs of different groups that the communicated message must successfully reach.

We acknowledge that such actions are far from easy. Within an environment of high uncertainty regarding the basic virological characteristics of the disease, selecting the appropriate messages and interventions to persuade others to behave in a specific and possibly self-defeating manner is a complex exercise that is wrought with a high potential for failure. This challenge is further compounded by pre-existing inequalities in group tensions that will only make it more difficult to align behaviors behind government strategy. Nor does the challenge become easier over time (quite the opposite), where initial framings of high uncertainty and high risk events like a pandemic are likely to align at the early onset of disease, yet grow more fragmented and less anchored around basic scientific debates as time goes on. As such, miscommunication must become far more nuanced and adaptive as group cleavages solidified.

Lastly, even the most expertly crafted risk communication campaign that successfully delivers effective messages to various majority and minority groups is destined to fail unless it is supported by policies that are seen as just, equitable, and supportive of unique needs of respective groups. At a minimum, there must be trust that policymakers will eventually meet or exceed these needs. As a core principle of transparency, honesty, and a long-standing commitment to deliver the correct strategy, miscommunication is predicated upon proactive policymakers and other response stakeholders to prevent extreme inequities, or not allow personal or group sacrifices (particularly when a social dilemma incentivizes them in an approach counter to government desires) to go underpaid or uncorrected.

Social dilemmas can and will continue to plague a considerable number of major policy disputes that affect communities around the world. They simply cannot be prevented. However, with appropriate interventions, a trusted and committed governing stakeholder, and a risk communication strategy that is tailored to the needs, expectations, and belief systems of various groups and stakeholders, such social dilemmas can be mitigated or even resolved over time, even in the midst of something as anxiety-inducing as a pandemic. Instead, the lingering question is whether or not leadership figures have the resources in patients to venture along this path, and take the difficult yet appropriate steps necessary to develop trust, equity, and fairness within a system that fundamentally is not engineered or designed to be so.

Disclaimer: The views and opinions expressed in this article are those of the individual authors and not those of the U.S. Army or other sponsor organizations.

References

Allen C, Angeler D, Garmestani A, Gunderson L, Holling C (2014) Panarchy: theory and application. Ecoystems 17:578–589

Bernardo F, Palma-Oliveira JM (2016) Urban neighborhoods and intergroup relations: the importance of place identity. J Environ Psychol 45:239–251. http://dx.doi.org/10.1016/j.jenvp.2016.01.010

Bernardo F, Palma-Oliveira J (2016) Identification with the neighborhood: discrimination and neighborhood size. Self Identity. 10.1080/15298868.2016.1178665

Brewer MB (1991) The social self: on being the same and different at the same time. Pers Soc Psychol Bull 17:475–482

Cuddy A, Fiske S, Glick P (2008) Warmth and competence as universal dimensions of social perception: the stereotype content model and the BIAS map. In: Zanna M (ed) Advances in experimental social psychology 40. https://doi.org/10.1016/s0065-2601(07)00002-0

Dawes RM (1980) Social dilemmas. Annu Rev Psychol 31:169–193.

Ostrom E (1990) Governing the commons: the evolution of institutions for collective action. Cambridge University Press

Florin MV, Nursimulu A, Trump B, Bejtullahu K, Pfeiffer S, Asquith M, O'Brien J et al (2018) Guidelines for the governance of systemic risks: in systems and organizations in the context of transitions. ETH Zurich

Hardin G (1968) The tragedy of the commons. Science 162:1243–1248

Hynes W, Trump B, Love P, Linkov I (2020) Bouncing forward: a resilience approach to dealing with COVID-19 and future systemic shocks. Environ Syst Decis: 1–11

Messick DM, Brewer MB (1983) Solving social dilemmas: a Review. In: Wheeler L, Shaver P (eds) Review of personality and social psychology, vol 4. Sage, Beverly Hills, CA, pp 11–44

Palma-Oliveira JM, Trump BD (2016) Modern resilience: moving without movement. IRGC Res Guide on Resilience, 173

Palma-Oliveira J, Trump BD (2018) Resilience: moving forward from a metaphor. In: Trump BD, Florin M-V, Linkov I (eds) IRGC resource guide on resilience (vol. 2): domains of resilience for complex interconnected systems. Lausanne, CH: EPFL International Risk Governance Center. on irgc.epfl.ch and irgc.org

Palma-Oliveira J, Trump B, Wood M, Linkov I (2018) Community-driven hypothesis testing: a solution for the tragedy of the anticommons. Risk Anal. https://doi.org/10.1111/risa.12860

Parks C, Vu A (1994) Social dilemma behavior of individuals from highly individualist and collectivist cultures. J Confl Resol. 10.1177%2F0022002794038004006

Ricoca-Peixoto M, Garrido MP, Greer D, Cruz F, Sarroeira AB, Palma-Oliveira JM (2020) Mapas mentais do SARS-CoV-2 e Covid-19 numa amostra de idosos em Portugal. Faculdade de Psicologia, Universidade de Lisbon

Rowell D, Connelly LB (2012) A history of the term "moral hazard". J Risk Insur 79(4):1051–1075

Silvers R (2012) The value of information in a principal–agent model with moral hazard: the ex post contracting case. Games Econ Behav 74(1):352–365. See also Garcia-Marques (2020) https://essentiallypsychology.com/o-risco-moral-e-juventude-na-pandemia/

Turner J (2005) Explaining the nature of power: a three-process theory. Eur J Social Psychol 35:1–22. https://doi.org/10.1002/ejsp.244

Walker B, Holling CS, Carpenter SR, Kinzig A (2004). Resilience, adaptability and transformability in social–ecological systems. Ecol Soc 9(2):5. http://www.ecologyandsociety.org/vol9/iss2/art5

Chapter 13
Inclusive Communication to Influence Behaviour Change During the COVID-19 Pandemic: Examining Intersecting Vulnerabilities

Susan Anson, Diotima Bertel, and James Edwards

Abstract The ongoing COVID-19 pandemic and its accompanying "infodemic" lend new urgency to the study and practice of risk communication. Especially prior to the distribution of vaccines in early 2021, our primary means of responding to the pandemic has been to communicate accurate information about risks and protective actions to the public. It is particularly crucial to effectively communicate such information to vulnerable groups, which is to say those that are especially susceptible to harm: this includes persons with underlying health conditions or disabilities, elderly people, the socioeconomically disadvantaged, and ethnic and linguistic minorities, among others. This task, however, is complicated by the facts that these groups are often difficult for risk communicators to reach and sometimes vulnerable to disinformation as well as to disease. After highlighting the role of risk communication in COVID-19 governance, this chapter examines the Protective Action Decision Model (PADM) as an appropriate tool for assessing the impact of individual- and group-level vulnerabilities on information channel access and preference, perceptions of threats, and assessments of risks and protective behaviours. Particular attention is given to the way vulnerabilities intersect to aggravate both negative health outcomes and information deficits. The chapter closes by advocating empirically-grounded risk communication strategies that take social complexity and the lived experiences of vulnerable groups into clear and intentional account.

Keywords Inclusive communication · Communication during COVID-19 · Vulnerable groups · Information deficits · Protective action decision model (PADM)

S. Anson (✉)
Trilateral Research, London SW1X 7QA, UK
e-mail: Susan.Anson@trilateralresearch.com

D. Bertel
SYNYO GmbH, Vienna, Austria

J. Edwards
SINUS Markt- und Sozialforschung GmbH, Berlin, Germany

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_13

13.1 Introduction

Risk communication is at the core of successfully assessing and managing risks (International Risk Governance Council—IRGC 2005). It refers to the process of exchanging risk-related information between actors and communicating it to the public (Reynolds and Seeger 2005; IRGC 2017). However, risk communicators often address “the public” as a homogeneous group (Purohit and Mehta 2020). This is counterproductive, as different groups within society have differential information needs and behaviours. Risk communication strategies and measures that focus only on the needs of the majority may unwittingly exclude minority groups, or even aggravate their vulnerabilities.

This chapter identifies vulnerabilities—defined as “conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of [an individual or] a community to the impact of hazards”—as crucial considerations in risk communication in general, and in communication on health crises such as COVID-19 in particular (UN/ISDR, Geneva 2015; cited in the Hyogo Framework for Action 2005–2015). Policymakers and public health experts unanimously recognise the disproportionate impacts of pandemics on vulnerable groups, including persons with underlying health conditions (Heffelfinger et al. 2009); elderly people (Gerst-Emerson and Jayawardhana 2015); pregnant women (Rasmussen et al. 2009); children (Stevenson et al. 2009); persons with disabilities (Campbell et al. 2009); Black, Asian Minority Ethnic (BAME) groups (Khunti et al. 2020); low-income and socially disadvantaged persons (Bouye et al. 2009); immigrants and refugees (Truman et al. 2009); and homeless persons (Leung et al. 2008). Many of the same factors that increase vulnerability to pandemics also impact information behaviour, and accordingly, if and how risk communication is received, understood and acted upon. This chapter views the information needs of vulnerable groups from a risk governance perspective. After highlighting the role of risk communication in COVID-19 governance, the authors examine the Protective Action Decision Model (PADM) (Lindell and Perry 2012) as a promising tool for assessing the impact of individual- and group-level vulnerabilities on information channel access and preference, subjective perceptions of threats, and subjective assessments of risks and protective behaviours. Particular attention is given to the way discrete vulnerabilities intersect to aggravate both negative health outcomes and information deficits. The chapter closes by advocating empirically-grounded risk communication strategies that take social complexity and the lived experiences and decision-making heuristics of diverse target audiences into clear and intentional account.

13.2 Governing COVID-19 Risks Through Communication

Since its emergence in December 2019, COVID-19 has had a profound global impact. The ongoing response requires actions from a variety of stakeholders to identify and adopt both policies to reduce infection rates and countermeasures to minimise the adverse side-effects of these policies. **Risk governance** is the gestalt process of coordinating all such actions concerned with “how to deal with demanding public risks” (van Asselt and Renn 2011, p. 434). The risk governance concept provides a framework for examining the complex processes and decision chains involved in identifying, assessing, managing, and communicating risks such as pandemics (IRGCa n.d.).

The International Risk Governance Council (IRGC 2005) has developed a risk governance framework that recommends an inclusive approach involving multiple stakeholders (IRGCb no date). This framework has subsequently been revised by Klinke and Renn (2012) and Renn et al. (2011) to include the following activities: (1) pre-estimation; (2) interdisciplinary risk estimation; (3) risk characterisation; (4) risk evaluation; and (5) risk management. Risk communication measures necessarily cross-cut all five activities. Situating COVID-19 responses within this framework provides a structured means of analysing communication gaps that have emerged as the crisis unfolds.

The first element of the risk governance framework, pre-estimation, is concerned with the ways in which different stakeholders select and interpret different phenomena as relevant risk topics (Renn 2008). It is human actors that create and select risks, with some risks being deemed worthy of consideration and other risks being ignored (Renn et al. 2011). This selection ultimately determines the risks that are communicated to the public. However, even when risks are identified as being worthy of consideration, there can be gaps in communicating them to relevant stakeholders. For instance, while the UK Cabinet Office identified pandemic influenza as being highly likely and having the largest possible impact in its 2008 National Risk Register, gaps still existed in terms of communicating this to the public. The UK government undertook “Exercise Cygnus” in October 2016 to assess the domestic preparedness for and response to an influenza pandemic (Public Health England 2017). Lessons that Croydon Council, a UK local government organisation, learnt from Exercise Cygnus included the need for “a better understanding of the likely public reaction” to a pandemic to “help the development of a robust communications strategy to assist the response” (Nuki and Gardner 2020). While there have been many debates over whether COVID-19 constitutes a “black swan” event, the fact that multiple governments included pandemics in risk registers and warned of pandemics being a question of “if” and not “when” suggests that it is not. Thus, any communication gaps are not a result of COVID-19 being entirely unanticipated, but are instead due to a lack of planning and preparedness that failed to consider different groups within society, their medical and socioeconomic vulnerabilities, and their different information needs.

The second element of the risk governance framework, interdisciplinary risk estimation, involves (1) assessing risks to human health and the environment, and (2) assessing concern (Renn et al. 2011). Different levels of complexity, uncertainty, and ambiguity can pose challenges to the risk assessment process and ultimately the communication of risk. As outlined above, pandemics disproportionately impact different vulnerable groups, and while it is understood that a number of factors influence the spread and/or impact of COVID-19, there is a need for further research to understand the complexity of these different factors. Additionally, COVID-19 is characterised by limited and changing knowledge, which underscores the need to provide clear communication updates. For example, in the early stages of the COVID-19 crisis, the expert consensus on using ibuprofen to treat symptoms changed (Day 2020). If such changes are not communicated clearly and carefully, they can sow ambiguity and undermine trust. In terms of ambiguity and conflicting views of risk, the emergence of COVID-19 deniers who share misinformation and do not follow protective measures highlights the need for parallel communication strategies to target disbelief on the one hand and counter misinformation on the other.

Interdisciplinary risk estimation also involves examining the ways in which different individuals, social groups, and stakeholders perceive the risk, the issues they associate with the risk (Klinke and Renn 2012), and the asymmetrical social and economic implications of the risk (IRGC 2005). With COVID-19, there has been a disconnect between the policies that governments have communicated and the groups that are impacted by these policies. For instance, research undertaken in the UK by Atchison et al. (2020) found that some groups (e.g., lower income, BAME) were less likely to be able to follow protective measures such as working from home and self-isolation without suffering social and economic tradeoffs. The differential impacts of COVID-19 highlight the critical need to develop inclusive communications, based on empirical concern assessments, that address the information needs of different groups within the context of their living conditions. Furthermore, as Slovic (2020) makes clear, the concern assessment process must take account of different experiences, feelings, and social, cultural, and political values alongside quantifiable demographic and economic factors.

In terms of the third, fourth, and fifth elements—risk characterisation, evaluation, and management—it is crucial to recognise that judgements about risks, their tolerability, and their societal acceptability can change over time (Renn et al. 2011). COVID-19 provides a clear example of this: changing evaluations of the COVID-19 risk lead to changing risk mitigation recommendations and the need for frequent communication updates, some of which appear contradictory and have resulted in public confusion (Blouin-Genest et al. 2020). Different types of risk will require different risk management strategies, which can range from implementing strict risk reduction measures to doing nothing.

Risk communication, stakeholder engagement, and the consideration of context are cross-cutting aspects that run through all five elements of the risk governance framework (IRGCb n.d.). These cross-cutting aspects are key to creating conditions for the society-wide uptake of risk mitigation behaviours, as well as to building public confidence in the risk management decisions taken by authorities (EPFL IRGC 2020). The next section of this chapter focuses on reducing risk through the use of risk communication to achieve behavioural change.

13.3 Targeting Risk Communication to Achieve Behavioural Change

The crucial element of any risk communication activity is to reach a specified target audience in a timely manner, thereby helping to ensure compliance with risk management measures and other positive behavioural changes. As outlined above, different risks may require different management approaches, and risk communication enables relevant stakeholders to understand the risk, the justification for the management approach adopted, and their role within this approach (IRGC 2017). A typical risk communication activity, for instance, is informing citizens of preparedness actions they can take to enhance their response to different types of disasters (e.g., creating an emergency grab bag, making a plan, and identifying local and regional resources).

As the COVID-19 pandemic makes clear, however, the importance of effective risk communication is not limited to acute disasters. In the absence of a vaccination or approved treatment prior to December 2020, the response to COVID-19 required rapid and widespread behaviour change to reduce the spread of the virus (Betsch et al. 2020). Authorities can use different tools to facilitate behaviour change, including risk communication and restrictions (Betsch 2020). Across the globe, countries are implementing different communication and different restriction policies with varying degrees of success. Risk communication is at the core of all such responses, providing citizens with knowledge of the protective behaviours recommended or mandated in order to reduce the spread of coronavirus. Examples of the different types of desired behaviours being communicated by governments include:

- Wearing a face mask
- Washing hands
- Maintaining a specified distance (e.g., 1–2 m) away from others
- Working from home where this is possible
- Restricting activities and contact with others through lockdowns, self-isolating and physical distancing.

13.3.1 The Protective Action Decision Model (PADM)

Research has highlighted a number of factors influencing the adoption of protective actions such as the above (Anson 2015). The Protective Action Decision Model

(PADM) is one model that outlines different factors influencing individuals' adoption of protective actions (Lindell and Perry 2012). It provides a framework that examines the different factors, in addition to risk communication, that influence the likelihood that a person will undertake protective actions. This chapter draws on the relevant components of the PADM and relates them to recent literature and research being undertaken in the context of pandemics and COVID-19.

The PADM includes a number of factors that influence the adoption of protective actions; environmental cues, social cues, information sources, channel access and preference, warning messages and receiver characteristics (Lindell and Perry 2012). Environmental cues include sights, smells or sounds that directly indicate a threat, whereas social cues include behaviours by others, which are taken in response to a threat or imply the presence of a threat (Lindell and Perry 2012). Related to the concept of social cues, Van Bavel et al. (2020) highlight how behaviour is influenced by social norms, the perception of what others are doing, and the expectation of social approval or disapproval. Approaches to COVID-19 in many countries have focused on appealing to existing social norms (e.g., washing hands) and creating new norms (e.g., staying at home) to facilitate behaviour change (Habersaat et al. 2020). Conformity to social norms can be a powerful motivating factor: a March 2020 survey conducted in Japan, for instance, found it to be "the most prominent driving force for wearing masks" (Nakayachi et al. 2020, p. 3). Of course, social norms can also spread unsafe behaviours: examples are the promotion of faith-based and ritual healing in some religious communities (Hashmi et al. 2020; Desta and Mulugeta 2020) and the false belief within anti-vaxxer circles that scepticism in vaccinations is widespread (French et al. 2020). Making safe behaviours normative requires authorities to engage community members in encouraging safe behaviours and discouraging unsafe behaviours, thereby making collective safety central to the group self-definition (Templeton et al. 2020).

In addition to environmental and social cues, the process of deciding whether to undertake protective action is often cued by warning messages sent from an information source, through a channel, to a receiver (Lindell and Perry 2012). With regard to the information source, research has shown that trust in both the authorities responsible for risk communication and others in general (interpersonal trust) plays a role in fostering compliance with the messages issued (in this case, regulations and measures to limit the negative effects of the pandemic). This is particularly evident in Sweden, where the initial government strategy to curb the pandemic was based upon voluntary compliance with expert advice rather than hard regulations: Esaiasson et al. (2020) demonstrate the importance of high institutional and interpersonal trust to the success of such an approach.

While limitations of the PADM, including conflicting and counterintuitive findings and untested propositions, have been identified by Lindell and Perry (2012), it provides a useful framework for considering the different factors involved in deciding to adopt protective actions. Four further elements in the model—receiver characteristics, channel access and preference, threat and protective action perceptions, and situational factors and impediments—are explored further in the next two sections (13.4 and 13.5).

13.3.2 The Need for Targeted Risk Communication

The World Health Organization's 2020 Call for Action on managing the COVID-19 infodemic establishes the importance of communicating information about COVID-19 "in ways that are actionable, and, where necessary, in ways that target specific vulnerable groups" (WHO 2020, p. 5). Targeting is crucial because many of the same social and individual factors that determine people's health vulnerabilities also impact their information behaviour and threat perceptions. Since the late 1980s, researchers and practitioners have paid increasing attention to the impact of such variables on risk communication in particular (Plough and Krimsky 2020). It is widely acknowledged that to increase the effectiveness of communication and adherence to the desired behaviours, authorities should take into account the social norms, information behaviour, and experiential realities of the particular groups they are targeting (Habersaat et al. 2020).

Targeting is particularly important because differing receiver characteristics can impact receivers' ability to follow the risk mitigation behaviours recommended by health authorities. Physical disabilities such as sight or hearing impairment, for instance, present hard barriers to the receipt of certain kinds of information. In addition to hard physical barriers, a range of demographic and sociocultural factors must be taken into account. Variables such as age, gender, level of education, race/ethnicity, language ability, technical ability, socio-economic status, religion, political orientation, and social milieu[1] can all impact information behaviour, group interest, and group self-definition. For instance, as outlined above, research undertaken in the United Kingdom found that despite a high willingness to self-isolate, respondents in the lowest household income bracket were six times less likely to be able to follow the recommended behaviour of working from home and three times less likely to be able to self-isolate (Atchison et al. 2020). Sociodemographic disadvantage is also associated with lower levels of trust in social institutions, including the healthcare system. Racial and ethnic minority communities, in particular, have often been subject to longstanding and pervasive discrimination, leading to differing patterns of trust. Members of these communities may be more likely to be wary about the public health information they receive, less likely to adopt recommended safety measures and potentially more susceptible to 'fake news', misinformation and conspiracy theories. This suggests the need for more targeted public health information and for partnerships between public health authorities and trusted organizations that are internal to these communities (Van Bavel et al. 2020). Health communication scientists indeed acknowledge that health disparities are driven by social and structural factors; the COVID-19 crisis has

[1]A social milieu is a group of people united by shared values and status, the interplay between which help determine everyday lifestyle (Hradil 2006). COVINFORM partner SINUS-Institut has conducted studies on the relationship between social milieu and information behaviour regarding health (Wippermann et al. 2011), career orientation (Calmbach and Edwards 2019), electoral politics (Vehrkamp and Wegschaider 2017), and other areas of life.

shown the need for new communication approaches, which move beyond a narrow focus on 'individual responsibility' (Dutta 2008; Viswanath 2006; Hull et al. 2020).

13.4 Intersecting Vulnerabilities and Information Behaviours

One complicating factor here is the intersectional nature of health vulnerabilities (Giritli Nygren and Olofsson 2014). The term intersectionality was first coined by critical race theorist Kimberlé Crenshaw (1989), and can be described as the "lens through which you can see where power comes and collides, where it interlocks and intersects" (Crenshaw 2017). Crenshaw describes how multiple dimensions of vulnerability often intersect in ways that complicate redress: for instance, black women face both gendered and racial employment barriers—or in this case, health vulnerabilities—whereas policy responses often assume a subject who faces only one such barrier or vulnerability (Crenshaw 1989, 1991). Risk communication needs to take into account the intersecting vulnerabilities that might prevent messages from being received by certain groups (Vardeman-Winter and Tindall 2010). Research on inclusiveness in science communication shows that failing to consider intersectional identities and the history that produced them can contribute to the reinforcement and reproduction of the systems that have marginalised people in the first place (Dawson 2019; Torres-Gerald 2019; Canfield et al. 2020; Kuran et al. 2020).

Three areas of particular concern which we will address below are channel access and preference, threat perceptions, and protective action perceptions.

13.4.1 Channel Access and Preference

Both empirical research and practical experience demonstrate that different groups often have different levels of access to various information channels (e.g. print, television, radio, and online). Different groups also often demonstrate usage preferences for certain channels or sources.

Physical disabilities offer a clear example of the variance in channel access and its impact on risk governance. Effectively communicating risks to the seeing-impaired, for example, not only requires developing audio-focused channels in addition to visually-focused channels such as online portals and television; it also requires tailoring the content of messages to ensure a high level of verbal description, including of information usually presented visually, such as geographic location (Sherman-Morris et al. 2020). Comparable challenges exist in relation to reaching the hearing-impaired (Engelman et al. 2017).

Language and cultural barriers are another clear example: risk communication messages will "be comprehended to the degree that [they] are conveyed in language that risk area residents understand" (Lindell and Perry 2003, p. 125). The disproportionate impact of disasters like Hurricane Katrina in the United States on minority and immigrant-background communities shows the importance of integrating non-majority languages and perspectives into risk communications planning from the ground up (Andrullis et al. 2007). It is not enough to simply translate majority-language materials: active input from minority communities is required to ensure that values and cultural factors are also taken into account, as these can impact trust (Perry et al. 1982).

Digital divides present an equally significant and in some ways more complex challenge. Van Dijk (2005) distinguishes between four interlinking categories of digital divides: motivational, material, skills, and usage. Early studies often focused on material access divides, for instance rural/urban infrastructure gaps or the availability of devices and subscription plans that low-income populations can afford (Selwyn 2004). However, motivational, skills, and usage divides can be equally significant (van Deursen and van Dijk 2015). The different types of access often correlate with each other, as well as with a range of demographic and sociocultural variables. For example, younger age groups are often more highly motivated and skilled in the use of social media, making channels like Facebook, Twitter, and Instagram potentially effective channels for youth-targeted risk communication, whereas television and radio are more appropriate means of reaching older groups (Collins et al. 2016).[2]

The intersectional nature of vulnerabilities can impact digital channel access in both expected and unexpected ways. In the Netherlands, for instance, income, education, age, and gender all directly affect material access, with education and age—but not income—additionally affecting skills and usage (van Deursen and van Dijk 2015). In the United States and other super-diverse countries, ethnicity/race has also been shown to impact ICT use, often in intersection with gender and socioeconomic status (Jackson et al. 2008). Such research casts doubt upon the assumption that improving material access to key information channels is alone sufficient to improve communications to vulnerable groups. Indeed, it highlights the harmful potential of such assumptions to place responsibility on vulnerable groups for improving their own information behaviour, while leaving unexamined the social causes of ingrained gaps in motivation, skills, and usage.

[2]This being said, age-based usage patterns are not the only factor that should be taken into account when planning social-media-based risk communication. Channel-specific perceptions also come into play: for instance, research highlights how Twitter is an effective channel to distribute government strategies, but not to spread factual information about viruses (Thelwall and Thelwall 2020). In part due to this, traditional mass media remains a crucial source for information about emerging health threats and disease outbreaks (Jardine et al. 2015; van Velsen et al. 2014).

13.4.2 Threat Perceptions and Protective Action Perceptions

Health, demographic, and sociocultural variables affect risk communications on the level of content as well as channel. Insofar as such factors condition human experience as a whole, they also invariably impact subjective perceptions of threats and protective actions (Lindell and Perry 2012). Vaughan (1995) describes this as a matter of *framing* and *weighting* risk issues and dimensions. *Framing* refers to the way a risk is initially conceptualised and defined, while *weighting* refers to the attachment of different degrees of importance to different dimensions of the risk situation, including the expected positive and negative outcomes of protective actions (Fischhoff 1983; Krimsky and Plough 1988). While risk communicators generally strive to present risk issues and protective actions in objective terms, their target audiences will invariably frame and weight these issues and actions in accordance with their subjective experiences, values, and concerns.

Physical disabilities offer perhaps the clearest example of the way different groups frame and weight risk dimensions differently. For instance, many of the measures taken to mitigate COVID-19, such as physical distancing and the avoidance of touch, are significantly less feasible for the Deaf-Blind community, who sometimes rely on touch for both communication and assistance with everyday tasks (Goggin and Ellis 2020). For some sight- and/or hearing-impaired citizens, the perceived risk of COVID-19 transmission through physical contact may not outweigh the perceived psychosocial and medical risks of recommended protective actions such as physical distancing. Failing to take such perspectives into account when designing communication strategies can easily lead to ableism, or the assumption of a "default subject" of policy who does not have disabilities (Mitchell and Snyder 2015, as cited in Goggin and Ellis 2020). While promoting measures such as physical distancing to the public as a whole is crucial, this must not be done in a way that presumes the universal capacity to take such measures or leads to the stigmatisation of groups with different risk complexes.

13.5 Barriers Within the Information to Behavioural Change Loop

As Sect. 13.3 stresses, the purpose of risk communication is often to motivate changes in behaviour, e.g. to promote protective behaviours and risk mitigation measures. The PADM, however, emphasises that the uptake of such measures depends on numerous factors other than access to the message: predecisional processes, situational factors (such as access to resources), perceived control over future outcomes, and perceptions of risk communicators and other stakeholders can all play a role as well (Lindell and Perry 2012).

13.5.1 Predecisional Processes

Receiving information about a hazard, such as COVID-19, will trigger the predecisional processes of exposure, attention and comprehension. Predecisional processes are semi-conscious cognitive and affective processes that condition whether people receive information, to what extent they pay attention to it, and how they comprehend it (Lindell and Perry 2012). Such processes are grounded in prior experiences, beliefs, and values: as Vaughan stresses, “individuals are not passive receivers of risk information, rather, communications are actively filtered through the ‘lens’ of a priori belief and value systems […] A priori beliefs may moderate the relationship between particular communications and eventual outcomes or responses” (1995, p. 175). Beliefs about risk in particular are often deeply rooted in the conditions of everyday life and past subjective experiences of well-being and distress, upon which inferences about the importance of certain kinds of information and the positive and negative outcomes of future behaviours are based (Dow and Cutter 2006). A different set of life experiences will inevitably lead to different ways of processing risk information and framing and weighting risk factors (Wachinger et al. 2013).

Debates over the trade-offs of lockdowns and physical distancing offer a salient example. On the one hand, lockdowns have been fairly conclusively shown to reduce COVID-19 transmission rates and deaths; at first glance, the bioethical case for lockdowns appears to be a simple matter of health over wealth (Li et al. 2020). However, this framing assumes a certain default position: that of subjects who might suffer economically and socially due to a lockdown, but whose lives and basic well-being would not be put at risk. This default position does not match the living conditions and experiences faced by numerous groups: for instance, those in absolute poverty (Broadbent et al. 2020); the mentally ill (National Academies of Science, Engineering and Medicine 2020); or women in abusive relationships (Gosangi et al. 2020; Schulz and Mullings 2006). For such groups, the health-vs.-wealth risk frame is radically insufficient, and attempted behavioural interventions that assumed such a frame would stand a chance of being rejected.

13.5.2 Situational Impediments and Facilitators

Even in cases in which risk communication audiences accept the communicators’ framing and perceive the negative consequences of the risk as outweighing the potential negative consequences of the recommended protective actions, they do not always take these actions. Here, situational factors are often at fault: “the actual implementation of behavioral response depends not only on people’s intentions to take those actions but also on conditions in their physical and social environment that can impede actions that they intended to take or that can facilitate actions that they did not intend to take” (Lindell and Perry 2012, p. 624). Risk communicators must take account of the fact that socioeconomically disenfranchised individuals and groups have less access to some resources and a narrower range of options available to them in some spheres of life, including with regard to risk aversion and mitigation. For example, poor communities are sometimes more likely to accept development projects that entail environmental and health hazards as long as they are also advertised as yielding economic benefits (Otway 1990). Likewise, individuals threatened with poverty are often more likely to accept or keep hazardous work—which, under COVID-19 conditions, could mean any job in front-line sectors. Taking an intersectional interpretive framework here is crucial, as demographic variables such as minority status often correlate negatively with access to resources and options (Iacobucci 2020; Duque 2020). In the UK, The Intensive Care National Audit and Research Centre "found that 35% of almost 2,000 [COVID-19] patients were non-white, nearly triple the 13% proportion in the UK population as a whole" clearly showcasing that Black, Asian Minority Ethnic (BAME) individuals are more heavily affected (Booth 2020). The reason for this is socio-economic, as well as the fact that BAME people are more likely to be employed in front-line positions. As outlined above, women are also at higher risk of exposure and risk of infection than men due to a higher proportion of women being employed in health care and caring roles.

13.5.3 Perceived Control Over Outcomes

Another, pervasive and pernicious barrier is a lack of perceived control. In general, individuals with limited socioeconomic resources tend to express more passive attitudes in the face of risk, less certainty about the quality and actionability of different data on risk, and a generally more precarious sense of control over outcomes in their lives, including health outcomes (Vaughan 1995). In many cases, beliefs about limited control must be deemed rational, as they are based on concrete experiences of disenfranchisement or suffering: for instance, experiences of racial discrimination (Peterson et al. 2020) and aging-related health problems can both degrade perceived control (Robinson and Lachman 2017). This fact poses a challenge to risk communicators, as prior beliefs about risk and perceptions of control over future outcomes tend to be quite resilient, and broader questions of resource distribution are outside their scope of action. Enhancing perceived control is a significantly more difficult task than ensuring that accurate information is readily available, especially when intersecting vulnerabilities are in play. In some contexts, participatory communications approaches focused on collaborating with and empowering communities have proven successful (Weinger and Lyons 1992).

13.5.4 Stakeholder Perceptions

Target audiences' perceptions of risk communicators also invariably impact their framing of risk issues and their likelihood of taking recommended protective actions. Here, power relations and trust are particularly crucial (Raven 1965, cited in Lindell and Perry 2012, p. 621). Individuals with a higher baseline level of trust in the authorities responsible for risk communication will be more likely to trust the information that they receive and be able to use this information to adopt recommended behaviours. A study of 25 European countries by Oksanen et al. (2020) identified institutional trust as a protective factor. This is consistent with findings on COVID-19 responses in China (Ye and Lyu 2020) and the United States (Sibley et al. 2020) as well as with research on the communication of other natural hazards such as floods and volcanic eruptions (Wachinger et al. 2013).

Here, again, an intersectional perspective is crucial insofar as it foregrounds the impact of power hierarchies and systems of discrimination (Schulz and Mullings 2006). For example, historical experiences of discrimination of racial and ethnic minority groups can lead to distrust in social institutions. Differences in the quality of health care—in terms of access, treatment options, prevention and health outcomes—reflect social inequalities across groups (Grabovschi et al. 2013; Duque 2020). Communities of colour and people with disabilities have historically been undertreated or abused through the medical system, and undocumented immigrants fear punitive measures should they present at a clinic or hospital (Berger et al. 2020).

13.6 Conclusion and Recommendations

The COVID-19 pandemic has had a profound impact on risk communication, validating some established theories and practices while bringing others into question. First, the magnitude and scope of its effects on a global scale are unique: while there are tested and agreed-upon strategies for communicating about natural disasters (e.g., flooding, wildfires) and man-made hazards (e.g., terrorism, industrial accidents), COVID-19 is a uniquely multifaceted crisis that requires multiple simultaneous approaches. Second, the ubiquity and unprecedented diversity of information and communications technologies distinguishes COVID-19 from other historical pandemics (Beaunoyer et al. 2020). Online networking has circumvented traditional gatekeepers and exponentially increased the number of channels and vectors along which good and bad information can flow, forcing a re-examination of risk communication as a practice and field of study. Existing group-level vulnerabilities aggravate these challenges significantly: even in countries with well-developed COVID-19 responses, the outbreak and its repercussions threaten the basic well-being of social groups whose lives and livelihoods are already precarious, while the uneven distribution of risk and suffering threaten to deepen inequalities and further divide societies. It is also possible that feedback effects can emerge between vulnerabilities to the pandemic itself and intersecting vulnerabilities to its accompanying infodemic, exponentially worsening both—this is among the questions that the European Commission-funded Horizon 2020 project COVINFORM will take up.

The complexities that distinguish COVID-19 will almost certainly characterise future systemic crises as well. Accordingly, it is imperative that researchers and practitioners approach the pandemic as a global living laboratory in which good and bad practices play out in real time. In the absence of a vaccine, government responses to COVID-19 at national and regional levels have largely focused on communication practices: e.g. disseminating accurate information, clarifying public health policies and guidelines, and encouraging risk mitigation behaviours such as 'social distancing' and proper hygiene (Fakhruddin et al. 2020).[3] The very different COVID-19 communication strategies being implemented by national and regional governments have yielded very different results. This provides scholars and practitioners with a unique opportunity to conduct comparative cross-national research and generate insights on the effectiveness of communication practices targeted toward different groups in different contexts. For instance, while the communication approaches of leaders such as New Zealand's Prime Minister Jacinda Arden have been evaluated positively, the approaches of leaders in other countries have been branded as failures (McGuire et al. 2020).

One factor distinguishing successful from unsuccessful communications strategies has been attention to the lived experiences of the intended audiences. With regard to at-risk groups and individuals, experiences of inequality, discrimination, and lack of control often shape the context within which messages about risks are framed and weighted. Such experiences can negatively impact the motivation and/or capacity to adopt recommended protective actions. Accordingly, focusing on the intersecting nature of vulnerabilities, inequalities, and the power structures that instantiate and reproduce them should be applied as a guiding principle, not only in everyday prevention, but particularly in risk and crisis management (Kuran et al. 2020). While this certainly challenges aspects of the existing crisis management playbook, a deeper understanding of intersectional vulnerability "allows [stakeholders] to tackle problematic power hierarchies and imbalances, take more specific and targeted actions in crises to protect so far neglected individuals, and formulate better and more targeted legislation" (Kuran et al. 2020, p. 6).

Bearing this in mind, several general recommendations can be made for communicating measures and practices during the COVID-19 crisis in an inclusive way to achieve desired behavioural changes. As mentioned above, the COVID-19 crisis was unprecedented in a number of ways: the risk situation and social risk awareness evolved and scaled up quickly, and due to the overwhelming presence of ICT,

[3]At the time this chapter was finalised in mid-December 2020, Pfizer-BioNTech vaccine distribution had just begun in the United States. The UK had just approved the Pfizer-BioNTech vaccine for emergency use, and the European Commission had announced its intention to reach an approval decision by the end of the month.

communication was carried out in an extraordinarily diffuse way. To effectively communicate in such a situation, first, a clear aim and objective of the communication is needed; this also influences the selection of the channels through which messages will be communicated. Aims and objectives include, for example, raising awareness; influencing perceptions of the risk; counteracting misperceptions of preventive measures (Geldsetzer 2020); instigating socially productive and resilience-based actions (e.g., in the form of two-way communication with different stakeholders to understand the benefits and barriers of recommended measures; see Atchison et al. 2020); or building trust and resolving conflict, as demonstrated by New Zealand's Prime Minister Jacinda Arden (Wilson 2020). It is important to adapt such aims and objectives as the situation evolves and changes.

Second, it is crucial to understand the context in which target audiences receive risk communication messages, as well as their drivers and barriers to action. Empirical research and direct engagement with target audiences can best achieve this goal. Levels of awareness and trust are relevant categories, as are differing behavioural norms and the social structures and power dynamics within a society. Conducting participatory research and proactive outreach in cooperation with groups that are particularly vulnerable to COVID-19, such as people with black and minority ethnic backgrounds, can help lead to a better understanding of how policies and communication can be developed (Devlin 2020). The authors would go so far as to argue that it is imperative for risk communicators to achieve an empirical understanding of their target groups, and to engage these groups in proactive outreach and cooperation, in order to ensure that risk information is received, understood, and acted upon as intended.

Risk communication can take place through a variety of communication channels, and research (Kano et al. 2011; Tanaka 2005) highlights the importance of using multiple channels. However, the nature of the COVID-19 crisis has restricted the use of certain channels. Face-to-face communication (e.g., in the form of community meetings), which traditionally facilitates two-way interaction and exchange with the public, has not been possible to the same extent as before the COVID-19 pandemic. As such, an increase in one-way communication via mass media, social media, online advertising, brochures, and direct mail has been inevitable. Such channels allow governments to share information, but they only allow audience voices to be heard to a limited degree. Social media, as an alternative or supplement to traditional media that enables two-way communication, has shown a significant increase in engagement compared to normal use during crises. While social media allows two-way communication with a large audience, an increasing amount of misinformation has also been shared, resulting in an infodemic (WHO n.d.). Persisting digital divides furthermore mean that certain audiences are excluded from information distributed via social media entirely, whereas the filter bubble phenomena means that certain audiences are excluded—or self-exclude—from certain (formally or informally closed) sub-networks and channels.

Finally, it is crucial to understand the effectiveness of COVID-19 communication. As such, ongoing research conducted with target audiences is needed to monitor and evaluate the effectiveness and impact of different communication strategies. Messages should be audience-tested and may include information on COVID-19 risks and symptoms; advice on which actions to take and which to avoid (e.g., physical distancing, washing hands, wearing face masks); indications of where to access trustworthy information; and briefs on the types of support available, etc. To be effective and avoid confusion, messages should be short, clear, and concise (Kuhlicke et al. 2016). In this context, it is important to consider the intersecting vulnerabilities that influence the interpretation of messages and uptake of protective actions, in order to understand barriers that may impede effective risk communication to particular vulnerable groups.

This being said, researchers and practitioners should avoid applying 'vulnerability' as a reified (i.e., static) category, and should take a constructively critical stance toward developmentalist and humanitarian narratives about the importance of reaching 'the most vulnerable'. Rather, they should place a sharp focus on questions of power and hierarchy, aiming to understand how power relations and inequalities shape life experiences. This means challenging normative narratives about the homogeneity of communities and seeking to critically situate human experience within a systemic analysis of power (Schulz and Mullings 2006). In this sense, risk communication researchers and practitioners need to heed the voices of vulnerable individuals and groups—while simultaneously challenging the concept of vulnerability and avoiding generalisations about vulnerability (Kuran et al. 2020), in order to avoid ontological assumptions of 'typical' or 'predefined' vulnerable groups (e.g., socio-economic status, demography). This imperative is delicate, but no more so than the social situation engendered by the pandemic.

Acknowledgements This article is the result of research activities of the COVINFORM project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101016247.

References

Andrullis DP, Siddiqui NJ, Gantner JL (2007) Preparing racially and ethnically diverse communities for public health emergencies. Health Aff 26(5):1269–1279. https://doi.org/10.1377/hlthaff.26.5.1269

Anson S (2015) The unequal segmentation of public preparedness for mass evacuation: a cross-national perspective (Unpublished doctoral thesis). Aston University, UK

Atchison CJ, Bowman L, Vrinten C, Redd R, Pristera P, Eaton JW, Ward H (2020) Perceptions and behavioural responses of the general public during the COVID-19 pandemic: a cross-sectional survey of UK Adults. medRxiv. https://www.medrxiv.org/content/10.1101/2020.04.01.20050039v1.full.pdf+html

Beaunoyer E, Dupéré S, Guitton MJ (2020) COVID-19 and digital inequalities: reciprocal impacts and mitigation strategies. Comput Hum Behav 106424. https://doi.org/10.1016/j.chb.2020.106424

Berger ZD, Evans NG, Phelan AL, Silverman RD (2020) Covid-19: control measures must be equitable and inclusive. BMJ 2020:368. https://doi.org/10.1136/bmj.m1141

Betsch C (2020) How behavioural science data helps mitigate the COVID-19 crisis. Nat Human Behav 4(5):438–438.https://www.nature.com/articles/s41562-020-0866-1
Betsch C, Wieler LH, Habersaat K (2020) Monitoring behavioural insights related to COVID-19. The Lancet 395(10232):1255–1256. https://doi.org/10.1016/S0140-6736(20)30729-7
Blouin-Genest G, Bogic A, Champagne E, Orozco NT, Burlone N (2020) The WHO's risky communication strategy created confusion around COVID-19. The Conversation, 2 July 2020. https://theconversation.com/the-whos-risky-communication-strategy-created-confusion-around-covid-19-140043
Bouye K, Truman BI, Hutchins S, Richard R, Brown C, Guillory JA, Rashid J (2009) Pandemic influenza preparedness and response among public-housing residents, single-parent families, and low-income populations. Am J Public Health 99(S2):S287–S293. https://doi.org/10.2105/AJPH.2009.165134
Booth R (2020) BAME groups hit harder by Covid-19 than white people, UK study suggests. The Guardian, 7 April 2020. https://www.theguardian.com/world/2020/apr/07/bame-groups-hit-harder-covid-19-than-white-people-uk
Broadbent A, Walker D, Chalkidou K, Sullivan R, Glassman A (2020) Lockdown is not egalitarian: the costs fall on the global poor. The Lancet 396(10243):21–22. https://doi.org/10.1016/S0140-6736(20)31422-7
Cabinet Office (2008) National risk register. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/61934/national_risk_register.pdf
Calmbach M, Edwards J (2019) Deutschland ist das Land der Chancen: Berufsorientierungen junger Gefluchteter. Eine qualitative SINUS-Studie, Springer VS
Campbell VA, Gilyard JA, Sinclair L, Sternberg T, Kailes JI (2009) Preparing for and responding to pandemic influenza: implications for people with disabilities. Am J Public Health 99(S2):S294–S300. https://doi.org/10.2105/AJPH.2009.162677
Canfield KN, Menezes S, Matsuda SB, Moore A, Mosley Austin AN, Dewsbury BM, Smith HM et al (2020) Science communication demands a critical approach that centers inclusion, equity, and intersectionality. Front Commun 5(2). https://doi.org/10.3389/fcomm.2020.00002
Collins M, Neville K, Hynes W, Madden M (2016) Communication in a disaster-the development of a crisis communication tool within the S-HELP project. J Decis Syst 25(sup1):160–170. https://doi.org/10.1080/12460125.2016.1187392
Crenshaw K (1991) Mapping the margins: intersectionality, identity politics, and violence against women of color. Stanford Law Rev 43(6):1241–1299
Crenshaw K (2017) Kimberlé Crenshaw on intersectionality, more than two decades later. https://www.law.columbia.edu/news/archive/kimberle-crenshaw-intersectionality-more-two-decades-later#:~:text=Crenshaw%3A%20Intersectionality%20is%20a%20lens,where%20it%20interlocks%20and%20intersects
Crenshaw K (1989) Demarginalizing the intersection of race and sex: a black feminist critique of antidiscrimination doctrine, feminist theory and antiracist politics. University of Chicago Legal Forum 1989:139–167
Dawson E (2019) Equity, exclusion and everyday science learning: the experiences of minoritised groups. Routledge
Day M (2020) Covid-19: ibuprofen should not be used for managing symptoms, say doctors and scientists. BMJ 368
Desta TT, Mulugeta T (2020) Living with COVID-19-triggered pseudoscience and conspiracies. Int J Publ Health 65:713–714. https://link.springer.com/article/10.1007%2Fs00038-020-01412-4
Devlin H (2020) Why are people from BAME groups dying disproportionately of Covid-19? The Guardian, April 22, 2020. https://www.theguardian.com/world/2020/apr/22/why-are-people-from-bame-groups-dying-disproportionately-of-covid-19. Last accessed May 18, 2020
Dow K, Cutter S (2006) Public orders and personal opinions: household strategies for hurricane risk assessment. Environ Hazards 2:143–155
Dutta MJ (2008) Communicating health: a culture-centered approach. Polity

Duque RB (2020) Black health matters too… especially in the era of COVID-19: how poverty and race converge to reduce access to quality housing, safe neighborhoods, and health and wellbeing services and increase the risk of co-morbidities associated with global pandemics. J Racial Ethn Health Disparit. https://doi.org/10.1007/s40615-020-00857-w

Engelman A, Ivey SL, Tseng W, Neuhauser L (2017) Risk perception and perceived self-efficacy of deaf and hard-of-hearing seniors and young adults in emergencies. J Emerg Manag 15(1):8–15. https://doi.org/10.5055/jem.2017.0309

EPFL IRGC (2020) Involving stakeholders in the risk governance process. IRGC Website. https://irgc.org/wp-content/uploads/2020/10/IRGC-Stakeholder-Engagement-Resource-Guide_Version2_2020-3.pdf

Esaiasson P, Sohlberg J, Ghersetti M, Johansson B (2020) How the coronavirus crisis affects citizen trust in government institutions and in unknown others. SocArXiv. April 30. https://doi.org/10.31235/osf.io/6yw9r

Fakhruddin B, Blanchard K, Ragupathy D (2020) Are we there yet? The transition from response to recovery for the COVID-19 pandemic. Prog Disaster Sci 100102. https://doi.org/10.1016/j.pdisas.2020.100102

Fischhoff B (1983) Predicting frames. J Exp Psychol Learn Mem Cognit 9(1):103–116. https://psycnet.apa.org/doi/10.1037/0278-7393.9.1.103

French J, Deshpande S, Evans W, Obregon R (2020) Key guidelines in developing a pre-emptive COVID-19 vaccination uptake promotion strategy. Int J Environ Res Public Health 17:5893. https://doi.org/10.3390/ijerph17165893

Geldsetzer P (2020) Knowledge and perceptions of COVID-19 among the general public in the United States and the United Kingdom: a cross-sectional online survey. Ann Intern Med. https://annals.org/aim/fullarticle/2763550/knowledge-perceptions-covid-19-among-general-public-united-states-united

Gerst-Emerson K, Jayawardhana J (2015) Loneliness as a public health issue: the impact of loneliness on health care utilization among older adults. Am J Public Health 105(5):1013–1019. https://doi.org/10.2105/AJPH.2014.302427

Giritli Nygren K, Olofsson A (2014) Intersectional approaches in health-risk research: a critical review. Sociol Compass 8(9):1112–1126. https://doi.org/10.1111/soc4.12176

Goggin G, Ellis K (2020) Disability, communication, and life itself in the COVID-19 pandemic. Health Sociol Rev 29(2):168–176. https://doi.org/10.1080/14461242.2020.1784020

Gosangi B, Park H, Thomas R, Gujrathi R, Bay CP, Raja AS, Seltzer SE, Balcom MC, McDonald ML, Orgill DP, Harris MB, Boland GW, Rexrode K, Khurana B (2020) Exacerbation of physical intimate partner violence during COVID-19 lockdown. Radiology 202866. https://doi.org/10.1148/radiol.2020202866

Grabovschi C, Loignon C, Fortin M (2013) Mapping the concept of vulnerability related to health care disparities: a scoping review. BMC Health Serv Res 13(94). https://doi.org/10.1186/1472-6963-13-94

Habersaat KB, Betsch C, Danchin M, Sunstein CR, Böhm R, Falk A, Fischer EF et al (2020) Ten considerations for effectively managing the COVID-19 transition. Nat Human Behav 4(7):677–687. https://doi.org/10.1038/s41562-020-0906-x

Hashmi FK, Iqbal Q, Haque N, Saleem F (2020) Religious cliché and stigma: a brief response to overlooked barriers in COVID-19 management. J Relig Health 59:2697–2700

Heffelfinger JD, Patel P, Brooks JT, Calvet H, Daley CL, Dean HD, Edlin BR, Gensheimer KF, Jereb J, Kent CK, Lennox JL, Louie JK, Lynfield R, Peters PJ, Pinckney L, Spradling Pl, Voetsch AC, Fiore A (2009) Pandemic influenza: implications for programs controlling for HIV infection, tuberculosis, and chronic viral hepatitis. Am J Public Health 99(S2):S333–S339. https://doi.org/10.2105/AJPH.2008.158170

Hradil S (2006) Soziale Milieus: Eine praxisorientierte Forschungsperspektive. Aus Politik und Zeitgeschichte 44–45:3–10. https://www.bpb.de/apuz/29429/soziale-milieus-eine-praxisorientierte-forschungsperspektive

Hull S, Stevens R, Cobb J (2020) Masks are the new condoms: health communication, intersectionality and racial equity in COVID-times. Health Commun 1–3. https://doi.org/10.1080/10410236.2020.1838095

Iacobucci G (2020) COVID-19: increased risk among ethnic minorities is largely due to poverty and social disparities, review finds. BMJ 2020;371:m4099. https://www.bmj.com/content/371/bmj.m4099/related

IRGC (International Risk Governance Council) (2005) Risk governance: towards an integrative approach

IRGC (2017) Introduction to the IRGC risk governance framework, revised version. EPFL International Risk Governance Center, Lausanne

IRGCa (n.d.) What is risk governance? IRGC Website. https://irgc.org/risk-governance/what-is-risk-governance/

IRGCb (n.d.) IRGC risk governance framework. IRGC Website. https://irgc.org/risk-governance/irgc-risk-governance-framework/

Jackson LA, Zhao Y, Kolenic A, Fitzgerald HE, Harold R, Von Eye A (2008) Race, gender, and information technology use: the new digital divide. Cyberpsychol Behav 11(4):437–442. https://doi.org/10.1089/cpb.2007.0157

Jardine CG, Boerner FU, Boyd AD, Driedger SM (2015) The more the better? A comparison of the information sources used by the public during two infectious disease outbreaks. PLoS ONE 10(10):e0140028. https://doi.org/10.1371/journal.pone.0140028

Kano M, Wood MM, Bourque LB, Mileti DS (2011) Terrorism preparedness and exposure reduction since 9/11: the status of public readiness in the United States. J Homel Secur Emerg Manag 8(1). https://doi.org/10.2202/1547-7355.1807

Khunti K, Singh AK, Pareek M, Hanif W (2020) Is ethnicity linked to incidence or outcomes of covid-19? BMJ 2020(369):m1548. https://doi.org/10.1136/bmj.m1548

Klinke A, Renn O (2012) Adaptive and integrative governance on risk and uncertainty. J Risk Res 15(3):273–292. https://doi.org/10.1080/13669877.2011.636838

Krimsky A, Plough S (1988) Environmental hazards: communicating risks as a social process. Auburn House, Dover, MA

Kuhlicke C, Begg C, Müller A, Karanci AN, Doğulu C, Konieczny R, Walczykiewicz T, Siudak M, Madej P, Shreve C, Anson S, Watson H, Wadhwa K, Mante C (2016) Report on the long-term learning framework for a multi- hazard context. Deliverable 8.2 of the TACTIC project, April 2016. https://zenodo.org/record/3775199#.XsLCzy-ZMdU

Kuran CHA, Morsut C, Kruke BI, Krüger M, Segnestam L, Orru K, Naevestad T Ol, Airola M, Keränen J, Gabel F, Hansson S, Torpan S (2020) Vulnerability and vulnerable groups from an intersectionality perspective. Int J Disaster Risk Reduct 101826. https://doi.org/10.1016/j.ijdrr.2020.101826

Leung CS, Ho MM, Kiss A, Gundlapalli AV, Hwang SW (2008) Homelessness and the response to emerging infectious disease outbreaks: lessons from SARS. J Urban Health Bull NY Acad Med 85(3):402–410. https://doi.org/10.1007/s11524-008-9270-2

Li HL, Jecker NS, Chung RYN (2020) Reopening economies during the COVID-19 pandemic: reasoning about value tradeoffs. Am J Bioeth 20(7):136–138. https://doi.org/10.1080/15265161.2020.1779406

Lindell MK, Perry RW (2003) Communicating environmental risk in multiethnic communities, vol 7. Sage Publications

Lindell MK, Perry RW (2012) The protective action decision model: theoretical modifications and additional evidence. Risk Anal Int J 32(4):616–632. https://doi.org/10.1111/j.1539-6924.2011.01647.x

McGuire D, Cunningham JE, Reynolds K, Matthews-Smith G (2020) Beating the virus: an examination of the crisis communication approach taken by New Zealand Prime Minister Jacinda Ardern during the Covid-19 pandemic. Hum Resour Dev Int 23(4):361–379. https://doi.org/10.1080/13678868.2020.1779543

Mitchell DM, Snyder S (2015) The biopolitics of disability: neoliberalism, ablenationalism, and peripheral embodiment. University of Michigan Press, Ann Arbor, MI

Nakayachi K, Ozaki T, Shibata Y, Yokoi R (2020) Why do Japanese people use masks against COVID-19, even though masks are unlikely to offer protection against infection? Front Psychol 11:1918

National Academies of Science, Engineering and Medicine (2020) Social isolation and loneliness in older adults. The National Academies Press, Washington, DC

Nuki P, Gardner B (2020) Exercise Cygnus uncovered: the pandemic warnings buried by the government. The Telegraph. https://www.telegraph.co.uk/news/2020/03/28/exercise-cygnus-uncovered-pandemic-warnings-buried-government/

Oksanen A, Kaakinen M, Latikka R, Savolainen I, Savela N, Koivula A (2020) Regulation and trust: 3-month follow-up study on COVID-19 mortality in 25 European countries. JMIR Public Health Surveill 6(2):e19218. https://doi.org/10.2196/19218

Otway H (1990) Communicating with the public about major hazards: challenges for European research. In: Gow HBF, Otway H (eds) Communicating with the public about major accident hazards. Elsevier, New York

Perry RW, Lindell MK, Green MR (1982) Crisis communication: ethnic differentials in interpreting and acting on disaster warnings. Soc Behav Personal 10(1):97–104. https://doi.org/10.2224/sbp.1982.10.1.97

Peterson LM, Stock ML, Monroe J, Molloy-Paolillo BK, Lambert SF (2020) Racial exclusion causes acute cortisol release among emerging-adult African Americans: the role of reduced perceived control. J Soc Psychol 160(5):658–674. https://doi.org/10.1080/00224545.2020.1729685

Plough A, Krimsky S (2020) The emergence of risk communication studies: social and political context. Sci Technol Human Values 12(3–4):4–10

Purohit N, Mehta S (2020) Risk communication initiatives amid COVID-19 in India: analyzing message effectiveness of videos on national television. J Health Manag 22(2):262–280

Public Health England (2017) Exercise Cygnus report. Tier one command post exercise pandemic influenza 18 to 20 October 2016. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/927770/exercise-cygnus-report.pdf

Rasmussen SA, Jamieson DJ, MacFarlane K, Cragan JD, Williams J, Henderson Z (2009) Pandemic influenza and pregnant women: summary of a meeting of experts. Am J Public Health 99(S2):S248–S254. https://doi.org/10.2105/AJPH.2008.152900

Raven B (1965) Social influence and power. In: Steiner I, Fishbein M (eds) Current studies in social psychology. Holt, Rinehart & Winston, New York, pp 371–382

Renn O (2008) Risk governance: coping with uncertainty in a complex world. Earthscan

Renn O, Klinke A, Van Asselt M (2011) Coping with complexity, uncertainty and ambiguity in risk governance: a synthesis. Ambio 40(2):231–246. https://doi.org/10.1007/s13280-010-0134-0

Reynolds B, Seeger MW (2005) Crisis and emergency risk communication as an integrative model. J Health Commun 10(1):43–55. https://doi.org/10.1080/10810730590904571

Robinson SA, Lachman ME (2017) Perceived control and aging: a mini-review and directions for future research. Gerontology 63:435–442. https://doi.org/10.1159/000468540

Schulz AJ, Mullings LE (2006) Gender, race, class, and health: intersectional approaches. Jossey-Bass

Selwyn N (2004) Reconsidering political and popular understandings of the digital divide. New Media Soc 6(3):341–362. https://doi.org/10.1177/1461444804042519

Sherman-Morris K, Pechacek T, Griffin DJ, Senkbeil J (2020) Tornado warning awareness, information needs and the barriers to protective action of individuals who are blind. Int J Disaster Risk Reduct 50:101709. https://doi.org/10.1016/j.ijdrr.2020.101709

Sibley CG, Greaves LM, Satherley N, Wilson MS, Overall NC, Lee CH, Mijolev P, Bulbulia J, Osborne D, Milfont TL, Houkamau CA, Duck IM (2020) Effects of the COVID-19 pandemic and nationwide lockdown on trust, attitudes toward government, and well-being. Am Psychol 75(5):618–630. https://doi.org/10.1037/amp0000662618

Slovic P (2020) Risk perception and risk analysis in a hyperpartisan and virtuously violent world. Risk Anal. https://doi.org/10.1111/risa.13606

Stevenson E, Barrios L, Cordell R, Delozier D, Gorman S, Koenig LJ, Odom E, Polder J, Randolph J, Shimabukuro T, Singleton C (2009) Pandemic influenza planning: addressing the needs of children. Am J Public Health 99(S2):S255–S260. https://doi.org/10.2105/AJPH.2009.159970

Tanaka K (2005) The impact of disaster education on public preparation and mitigation for earthquakes: a cross-country comparison between Fukui, Japan and the San Francisco Bay Area, California, USA. Appl Geogr 25(3):201–225. https://doi.org/10.1016/j.apgeog.2005.07.001

Templeton A, Guven ST, Hoerst C, Vestergren S, Davidson L, Ballentyne S, Madsen H, Choudhury S (2020) Inequalities and identity processes in crises: recommendations for facilitating safe response to the COVID-19 pandemic. Br J Soc Psychol 59(3):674–685. https://doi.org/10.1111/bjso.12400

Thelwall M, Thelwall S (2020) Retweeting for COVID-19: consensus building, information sharing, dissent, and lockdown life. arXiv:2004.02793

Torres-Gerald LE (2019) Speaking truth to power and to the people: scientist bloggers of color as public intellectuals. Graduate Theses and Dissertations. 17584. https://lib.dr.iastate.edu/etd/17584

Truman BI, Tinker T, Vaughan E, Kapella BK, Brenden M, Woznica CV, Rios E, Lichtveld M (2009) Pandemic influenza preparedness and response among immigrants and refugees. Am J Public Health 99(S2):S278–S286. https://doi.org/10.2105/AJPH.2008.154054

United Nations (2015) Hyogo framework for action 2005–2015: building the resilience of nations and communities to disasters. Extract from the final report of the world conference on disaster reduction (A/CONF.206/6). https://www.unisdr.org/files/1037_hyogoframeworkforactionenglish.pdf

Van Asselt MB, Renn O (2011) Risk governance. J Risk Res 14(4):431–449. https://doi.org/10.1080/13669877.2011.553730

Van Bavel JJ, Baicker K, Boggio PS, Capraro V, Cichocka A, Cikara M, Crockett MJ, Crum AJ, Douglas KM, Druckman JN, Drury J, Dube O, Ellemers N, Finkel EJ, Fowler JH, Gelfand M, Han S, Haslam SA, Jetten J, Kitayama S, Mobbs D, Napper LE, Packer DJ, Pennycook G, Peters E, Petty RE, Rand DG, Reicher SD, Schnall S, Shariff A, Skitka LJ, Smith SS, Sunstein CR, Tabri N, Tucker JA, van der Linden S, van Lange P, Weeden KA, Wohl MJA, Zaki J, Zion SR, Willer RJ (2020) Using social and behavioural science to support COVID-19 pandemic response. Nat Human Behav 1–12. https://doi.org/10.1038/s41562-020-0884-z

van Deursen AJAM, van Dijk JAGM (2015) Toward a multifaceted model of internet access for understanding digital divides: an empirical investigation. Inf Soc 31:379–391. https://doi.org/10.1080/01972243.2015.1069770

van Dijk JAGM (2005) The deepening divide: inequality in the information society. Sage, London, UK

van Velsen L, Beaujean DJ, van Gemert-Pijnen JE, van Steenbergen JE, Timen A (2014) Public knowledge and preventive behavior during a large-scale Salmonella outbreak: results from an online survey in the Netherlands. BMC Public Health 14(1):100. https://doi.org/10.1186/1471-2458-14-100

Vardeman-Winter J, Tindall NTJ (2010) Toward an intersectionality theory of public relations. In: Heath RL (ed) The SAGE handbook of public relations. Second Edition, SAGE, pp 223–235

Vaughan E (1995) The significance of socioeconomic and ethnic diversity for the risk communication process. Risk Anal 15(2):169–180. https://doi.org/10.1111/j.1539-6924.1995.tb00311.x

Vehrkamp R, Wegschaider K (2017) Populäre Wahlen: Mobilisierung und Gegenmobilisierung der sozialen Milieus bei der Bundestagswahl 2017. Bertelsmann Stiftung. https://www.bertelsmann-stiftung.de/de/publikationen/publikation/did/populaere-wahlen/

Viswanath K (2006) Public communications and its role in reducing and eliminating health disparities. Examining the health disparities research plan of the National Institutes of Health: unfinished business. Institute of Medicine, Washington, DC, pp 215–253. National Academies of Sciences

Wachinger G, Renn O, Begg C, Kuhlicke C (2013) The risk perception paradox: implications for governance and communication of natural hazards. Risk Anal 33(6):1049–1065

Weinger M, Lyons M (1992) Problem solving in the fields: an action-oriented approach to farmworker education about pesticides. Am J Ind Med 22:677–690. https://doi.org/10.1002/ajim.4700220506

Wilson S (2020) Three reasons why Jacinda Ardern's coronavirus response has been a masterclass in crisis leadership. The Conversation, April 5, 2020. https://theconversation.com/three-reasons-why-jacinda-arderns-coronavirus-response-has-been-a-masterclass-in-crisis-leadership-135541

WHO (n.d.) Infodemic. WHO Website. https://www.who.int/health-topics/infodemic#tab=tab_1

WHO (2020) An ad hoc WHO technical consultation managing the COVID-19 infodemic: call for action, 7–8 April 2020. World Health Organization, Geneva

Wippermann C, Arnold N, Möller-Slawinski H (2011) Chancengerechtigkeit im Gesundheitssystem. VS Verlag, Wiesbaden

Ye M, Lyu Z (2020) Trust, risk perception, and COVID-19 infections: evidence from multilevel analyses of combined original dataset in China. Soc Sci Med 265:113517. https://linkinghub.elsevier.com/retrieve/pii/S027795362030736X

Chapter 14
Between Resilience and Adaptation: A Historical Framework for Understanding Stability and Transformation of Societies to Shocks and Stress

John Haldon, Annelise Binois-Roman, Merle Eisenberg, Adam Izdebski, Lee Mordechai, Timothy Newfield, Philip Slavin, Sam White, and Konrad Wnęk

Abstract How environmental stress affected past societies is an area of increasing relevance for contemporary planning and policy concerns. The paper below examines a series of case studies that demonstrate that short-term strategies that sustain a state or a specific bundle of vested interests did not necessarily promote longer-term societal resilience and often increased structural pressures leading to systemic crisis. Some societies or states possessed sufficient structural flexibility to overcome very serious short-term challenges without further exacerbating existing inequalities. But even where efforts were made consciously to assist the entire

J. Haldon (✉)
Princeton University, Princeton, USA
e-mail: jhaldon@princeton.edu

A. Binois-Roman
University of Paris 1 (Sorbonne), Paris, France

M. Eisenberg
National Socio-Environmental Synthesis Center (Annapolis), Annapolis, USA

A. Izdebski
Max-Planck-Institute for the Science of Human History, Jena, Germany

L. Mordechai
Hebrew University of Jerusalem, Jerusalem, Israel

T. Newfield
Georgetown University, Washingtonm, USA

P. Slavin
University of Stirling, Stirling, UK

S. White
Ohio State University, Columbus, USA

K. Wnęk
Jagiellonian University, Kraków, Poland

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_14

community the outcome often generated unpredictable changes with negative longer-term impacts. Greater degrees of baseline socio-economic inequality at the outset of a crisis are associated with less resilience in the system as a whole, a more uneven distribution of the resilience burden, and an increased risk of post-solution breakdown of a given social order. The historical case studies therefore indicate that future policy planners must consider structural socio-economic imbalances when designing and implementing responses to environmental challenges.

Keywords Environmental history · Historical resilience · Societal resilience · Socio-economic inequality

14.1 Introduction

How environmental stress affected historical societies is an area of social science that remains underdeveloped. As an interdisciplinary area of interest that includes historians, archaeologists, social anthropologists and economists, among others, it remains fragmented in terms of approach and scientific vocabulary, with substantial disagreements among scholars. What type and magnitude of environmental stress would precisely constitute an existential risk to a given historical society, that is to say, a risk that could trigger the collapse of a political or cultural system, can be defined both objectively, by an external or a modern observer on the basis of a set of agreed criteria, as well as subjectively, by the inhabitants of the society in question, or their successors. Both are relevant since perceptions and understanding determine responses and reactions, and because the logic and rationality of a past social-cultural system will often be very different from our own.

History is above all about how and why things changed through time. Fundamental to this is the question of the relationship between agency and structure —about the relationship between what people believed about themselves and the world they inhabited (and how they perceived it) and how this affected their actions upon and within it. The degree to which key ideas—conveyed through a religious ideology or a political theology of rule—penetrated to the roots of a past society affected both the way in which people understood and responded to the challenges they faced, or whether they perceived them at all, as well as the means through which a cultural system held together under stress. The extent to which the beliefs and ideology of the dominant political elite are relevant for the day-to-day interests and identities of the mass of the population have a crucial impact on social cohesion. All of the above are significant factors in how a given state system organizes its control of resources or whether it has the internal strength or flexibility to weather particular political, social or economic moments or longer periods of pressure. It is only by taking them all into account and disentangling the overlaps, linkages and mutual interactions that we can hope to glimpse something of the mechanisms behind societal responses (Goldstone and Haldon 2009).

Historical research can reveal the extent to which rulers and elites, or farmers and producers, attempted to mitigate risk and absorb future shocks. Many of their responses were moral and religious. Although we would often not consider such responses practical, it is important to bear in mind that in the pre-modern/pre-scientific world they had clear practical implications. Moving sacred relics to a city to protect it from earthquakes, for example, may not have reduced the mortality of subsequent earthquakes. But it did reinforce social cohesion and thus offer a type of resilience that facilitated the survival of the urban community. Recent experience with COVID-19 has demonstrated quite clearly that our 21st century responses are not as practical as we like to think. Moral and religious ideological responses did little to reduce the number of infections and deaths, but nonetheless helped people cope with their changed circumstances.

Why and when do some socio-political systems—or their constituent parts—break down? What permits other systems to survive traumatic structural and conjunctural damage? The study of complex historical societies can reveal how socio-environmental challenges worked to transform structural relationships and daily life, what are the structural limitations to resilience and how they were configured as aspect of a systemic whole, as well as what happened when the dust settled and how both leaders, governments and the members of a society re-evaluated their situations. In this chapter, we show both that system recovery depended not only on system structure and capacity, but also that belief systems and ideological assumptions constituted a significant aspect of system capacity, a factor often ignored or misunderstood in analyses of the responses of past (and present) societies. We suggest how some pre-industrial societies responded to transformative and unpredictable environmental pressures. But we also note that what can in the short-term be a resilient response at one level of a society—that is to say, a response that tends towards the maintenance of the established system—may well turn out to address only the symptoms of a challenge and thus be insufficient or even maladaptive from a systemic perspective, one aspect of the 'rigidity trap' that inhibits structural responses sufficient to absorb or redress an imbalance. A common thread of these historical examples is a tendency of system recoveries to focus on elite-level actors, rather than the far more numerous non-elite members of a society (although this may sometimes reflect the bias of our sources, as we will see below). As some of these cases demonstrate, a more just and equitable resilience can lead to longer term stability for a state and its institutions.

We treat social-cultural systems heuristically as complex and adaptive, consisting of linked or nested multi-scale sub-systems (Gunderson and Holling 2002; Holling 2001) in which cycles of change and adaptation at sub-systemic level intersect with larger, slower processes. In consequence, catastrophic system-wide change at the higher level only takes place when there is a coincidence in the level of vulnerability or fragility among all or most of the different adaptive cycles from which the system as a whole is composed. Without such a convergence there can be no breakdown or collapse (Cumming and Peterson 2017).

At smaller spatial and temporal scales, these sub-systems experience continuous change as they move through each phase of their own particular developmental cycle. In so doing they act to maintain the identity of the system over the long term, thus facilitating a built-in elasticity and capacity for adaptation without fundamental change. As our examples show, this conceptual model offers an appropriate heuristic framework through which to understand the limits of resilience as well as longer-term historical societal transformation (Haldon and Rosen 2018; Walker et al. 2004). In particular it helps to understand the ways in which elements of a system can transform or break down while the basic shape and trajectory of the system as a whole is preserved, on the one hand, and on the other to determine the point by which, once a sufficient number of such sub-elements have been transformed, a system as a whole can be said to have taken on a new systemic identity.

An important aspect of this is the observation, first, that the more complex a system becomes, the finer the balance between its mutually-interdependent parts and the greater the potential for disequilibrium when one feature becomes unstable, generating a domino-effect breakdown of the whole (e.g. Dark 2016). Secondly, however, the greater the diversity of systemic processes, the greater the potential for systemic redundancies and thus greater resilience. This approach is useful in thinking about large-scale systemic breakdown in, for example, patterns of trade and exchange, as well as in respect of international political systems (Sherrat 2003: 53–54; Bell 2006: 15). Complex systems may thus also demonstrate great flexibility, and the key to such resilience is another important element in any historical research program (e.g. Rosen 2007). Since the basic structural dynamics of a societal system determine the types of collapse it is most likely to experience, approaches to collapse and resilience that unite structure and process are the best way forward in applying historical examples to contemporary planning initiatives, especially when allowances are made for individual human agency and belief systems (Cumming and Peterson 2017; Haldon et al. 2020; also Anderies 2006; Berkes and Ross 2016; Gunderson and Holling 2002).

Looked at from this perspective, total systemic collapses—the synchronic breakdown of a whole socio-economic system—were rare even in cases of severe stress, whether environmental or societal. System transformations there certainly were, but these entailed incremental breakdowns of specific sub-systems within the totality of social-cultural relations, often as part of centuries-long processes. While such processes did indeed result in systemic transformation that we can describe as a transition from one state to another, the commonly uncritical use of the term collapse gives a fundamentally flawed impression of the complex processes that were in fact involved (Haldon et al. 2020).

14.2 Methodological Considerations

Decades of scholarship considered medieval farmers rigid and largely helpless against the vagaries of the natural world, but more recent work has underscored their adaptability (Stone 2005). Both short-term coping strategies, which could be adopted or deployed rapidly during acute environmental stress, and long-running socio-cultural and economic structures that facilitated resilience and expanded the capacity to respond to changes in the natural world, have come to light. Premodern cultures had ways of dealing with different degrees of uncertainty and were well able to manage known environmental risks such as occasional flooding or short-term drought. Explanations for such events, and ways of mitigating their impacts, were part of the annual cycle of life. States were generally capable of assessing political risks to their territory or their continued independent existence and building appropriate defensive capacity—not always successful over the longer term, but certainly indicative of an ability to plan for potential and actual future challenges and risks. Similarly, societies were prepared to mitigate, at least partially, the economic consequences of animal losses following epizootics or environmental stress. While major instances of any of these could overburden any society's capacity to absorb the shock, past human societies as a whole have been remarkably resilient in the face of severe challenges, regularly adapting even when the challenges impacted the configuration of their social and political structures (Haldon and Rosen 2018; Rosen 2007).

Three factors have had a major influence on how past social systems responded to stress: their complexity (the degree of interdependency across social relationships and structures), their institutional and ideological flexibility, and their systemic redundancy. Together, they determined the resilience of the system. These three factors did not exist in isolation but combined and recombined in innumerable historical configurations. Historians must reduce this complexity to ideal-typical models, since it is practically impossible to analyze them all. Only through researching particular historical case-studies can we show how each case is subtly different from the next and identify any patterns that may become evident.

There are, of course, costs to the ability of a society to maintain cohesion and cultural continuity through periods of system-challenging stress. How these differential costs of resilience were distributed and the degree to which they were built into a system varied across time and cultural milieu. Below we examine the differential costs of resilience when states are faced with substantial economic and political challenges, and we examine several historical cases where we can observe: (i) both top-down and bottom-up responses to significant short-term environmental challenges; how different sectors of society responded or reacted; and where we can detect positive as well as negative outcomes; and (ii) state and society-level responses to pandemics and both planned and unintended consequences.

14.3 Earthquakes: Beirut and the Earthquake of 551 CE

Recent research has called attention to the various anomalous environmental phenomena that took place during Late antiquity (c. 300–700 CE) around the Mediterranean and beyond. The list includes not only climatic changes, including the Late Antique Little Ice Age (mid-6th-later 7th c), and disease events, such as the Justinianic Plague (mid-6th-mid-8th c.), but also unusual seismic activity in the eastern Mediterranean, sometimes called the Early Byzantine Tectonic Paroxysm (mid-4th-mid-6th c.) (Pirazzoli et al. 1996; Pirazzoli 1986; Büntgen et al. 2016; Harper 2017). Although the Mediterranean in general and the Levant in particular are seismically active areas today, it appears that the area cycles between phases of low and high seismicity. While today we are in a low-seismicity phase, the sixth century featured a high seismicity phase in which the frequency of destructive earthquakes was about four times more frequent.

Many contemporary sources refer to the earthquakes that periodically hit the cities of the eastern Mediterranean, among the wealthiest and most urbanized areas in the sixth-century Roman Empire. These accounts tend to focus on the destruction associated with earthquakes. In the context of the seventh-century Persian and Islamic conquests of the region from the Romans, many scholars believed that the sixth-century earthquakes destroyed whole cities and disrupted the region's socio-economic fabric, weakening the Roman Empire and explaining unexpected Roman losses in the seventh century. Could earthquakes have such a long-term effect?

The city of Berytus (present-day Beirut, Lebanon), was the capital of a Roman province and a major regional center. It housed a law school that was renowned throughout the Eastern Mediterranean, to which students from far-flung provinces came to study. It was also one of the centers of the lucrative and prestigious Roman silk industry in the Eastern Mediterranean (Mordechai 2020). In 551, a major earthquake hit the eastern coast of the Mediterranean. The epicenter was likely a few kilometers offshore from Berytus. Scientific reconstructions estimate its local magnitude at 7.3–7.8. It is associated with uplifted areas of the coast by about a meter (Elias et al. 2007). In premodern times, such earthquakes often caused massive damage. Historical accounts indicate that the earthquake damaged many of the cities on the Levantine coast. The earthquake caused both a tsunami that hit Berytus, and a large fire, compounding the damage. Several key pieces of infrastructure, such as the city's aqueduct, were put out of service (John of Ephesus in Ps. Dionysius of Tel-Mahre: 135–136). The city sustained major short-term damage, which is corroborated by some urban archaeological excavations. One archaeologist described how the area she excavated revealed the earthquake's "horrors in an archaeological inferno" recorded in a meter-deep layer of destruction in some areas (Saghieh-Beydoun 2004).

The effects of the earthquake on the city are debated. The imperial government seems to have allocated some relief funds and appointed an official to preside over the rebuilding efforts. However, since Berytus receives almost no mentions in the sources thereafter, and in light of some of the archaeological excavations, many scholars interpreted the earthquake as destroying the city, or at least causing massive damage to it that led most of its inhabitants to abandon it (e.g. Kennedy 1985). Yet this interpretation does not fit one of these rare references to the city. A pilgrim who stopped in Berytus en route to the Holy Land twenty years after the earthquake describes the city in only a few words, which are nonetheless sufficient to suggest that Berytus remained a fairly large city. Puzzlingly, it refers to the city as "most splendid", a description that hardly meshes with the center's supposed decline (Piacenza Pilgrim: 159–160, also see Hall 2004; Mordechai 2020). Scholars who had noticed his account argue that the restored city was "a pale shadow of the former city" (e.g. Mikati and Perring 2006).

Parallel social developments: To understand the aftermath of the 551 earthquake, it is necessary to examine the city's broader social context by focusing on its two most conspicuous sectors in the pre-earthquake city's cultural capital—its law school and its silk industry. The law school had operated since c. 200 CE (equivalent to a modern-day Ivy League school), while the silk industry developed mainly over the fifth century. In the mid-sixth century, the dynamic emperor Justinian I (r. 527–565) attempted to reform and centralize various institutions in his empire.

As part of the emperor's legal reform, he centralized and standardized law education. Justinian first invited the most prominent professors from the Berytus school to Constantinople, where they were to help an imperial official codify and standardize Roman law over several years—a massive endeavor that resulted in a major law code, the so-called Corpus Iuris Civilis, which remains foundational for continental civil law today. The law professors who took part in the emperor's initiative undoubtedly established connections in the capital, and perhaps a few chose to stay and teach there after finishing their multiyear task. Justinian acknowledged the contribution of the Berytus professors by offering imperial sanction to the city's school alongside Constantinople and Rome as the only permitted law schools in the empire (Mordechai et al. 2020).

At the same time, the lucrative Roman silk industry was centered on the coastal cities of the Levant at least since the fifth century CE. The peace the Roman Empire enjoyed in the fifth century allowed this industry to develop through trade and growing specialization. When the wars between the Persian and Roman Empires reignited in the early sixth century, the trade networks of the cities of the Levant were disrupted, with deleterious effects on the silk industry in some of these cities. According to one ancient historian, some silk workers actually emigrated to Rome's enemy Persia in search of a better fortune (Procopius, *Secret History* 25.13–26). The local industry received another blow when emperor Justinian attempted to centralize silk trade and manufacturing in Constantinople.

It was in this context that the earthquake of 551 hit the Levant. Contemporaries are explicit about the immediate effects of the earthquake on the law school. The contemporary historian Agathias notes that the earthquake destroyed the law school building and killed many of its students. As part of the recovery from the earthquake, Justinian directed the law school to move south temporarily to Sidon, a city perceived negatively by contemporaries and seemingly less affected by the earthquake (Agathias, *Histories* 2.15.1–4). There is neither evidence that the law school move ever happened nor that the law school continued to operate in Berytus after 551, and the most plausible interpretation is that the earthquake led to the collapse of the law school. Some of the faculty chose to emigrate to Constantinople, some of the surviving students probably joined them while others returned home. Later generations of students would attend the single surviving law school—in the capital Constantinople (Mordechai 2020).

The silk industry also disappeared from Berytus, as no surviving source mentions the industry. The pilgrim who passed through the region after the earthquake noted that the neighboring city Tyre had a flourishing silk industry. Again, some of those involved in it moved to Constantinople, Tyre or elsewhere, and it seems that the silk trade moved away from Berytus and intensified around Tyre.

But it should be noted that both the law school and silk industry had become vulnerable decades before the earthquake by a combination of economic, cultural and social changes within the empire. In this context, the 551 earthquake can be thought of as a catalyst, the straw that broke the camel's back. The dissolution of both sectors—the loss of the city's cultural capital—also explains the disappearance of Berytus from the written sources. Since the city lost its most important cultural markers, contemporaries found little reason to pay it specific attention and write about it (Mordechai 2020). Yet life in the city did not stop. The government rebuilt the city, and, archaeological excavations have illuminated some of the other changes it went through in the aftermath of the earthquake. And based on the best measure of the city's economy, coins, it appears that economic activity continued at about the same level as before the earthquake (Abou Diwan 2018; Mordechai 2020).

While the earthquake caused much damage it also offered opportunities: local pottery production changed its fabric and firing, indicating that the production center in the city adapted and a different local source of clay was used (Reynolds and Waksman 2007). There is also evidence for shifts in trade routes. For example, while most cooking wares in Berytus before the earthquake were produced locally, after the earthquake archaeologists have found a major increase in imports from a workshop near present-day Acre, Israel, which was able to supply the city (Reynolds and Waksman 2007; Waksman et al. 2005). At the same time, Berytus began producing and using its own amphorae (large pottery jars for shipping goods such as olive oil or wheat) in greater volume than it had for centuries (Reynolds 2000). Other specialized industries, such as glass, saw changes as well, as the earthquake allowed for more experimentation. The diversity of glass vessel shapes, for example, increased only after the earthquake. Moreover, the many glass shards found in the excavations and the high-quality material they are made of suggest that glass recycling was rare, which in turn is another indicator that the city remained affluent (Jennings 2004–2005).

The Berytus case study reveals some of the tensions within the Roman state system. Policies formulated at the state level had drastic effects at the local level. External conditions introduced vulnerabilities that compounded over time to existing institutions. The earthquake hastened the end of existing industries and activities, including the law schools and silk industry. In spite of this, and the difficulties many locals suffered during and after the earthquake, it also created new opportunities, and a fair amount of locals were able to exploit the new circumstances to improve their economic situation.

14.4 Pandemics, 1: The Justinianic Plague

The Mediterranean political world at the onset of the sixth century CE contrasted radically with what had existed a century earlier. In the west, a coherent Roman imperial state had disappeared and was replaced with smaller successor states, including the Ostrogoths in Italy, the Vandals in North Africa, and the Visigoths, Burgundians, and Franks controlling different regions of Gaul (Heather 2005; Halsall 2007). In the east, the Roman Empire continued to control lands in the Balkans, Anatolia (Turkey), Syria, Palestine, and Egypt. By the year 540, the political situation had changed again and the Eastern Roman Empire, under its proactive emperor, Justinian had managed to reconquer North Africa, Italy, and parts of southern Iberia. Despite these shifting political realities, the Eastern Roman economy remained robust (Heather 2018; Sarris 2006).

The deeply connected and flourishing economy in the east simultaneously helped spread the bacterium *Yersinia pestis* (causative agent of the plague), which is first reported in Egypt in 541, and likely spread from there on commercial ships and overland trade across the Eastern Mediterranean region, reaching the capital of Constantinople (Istanbul) within a year and the rest of Europe within a few years (*Procopius, Wars,* II. xxii–xxiii)… This was the initial outbreak of first plague pandemic commonly known as the Justinianic Plague (c. 541–750 C.E.). Other contemporary writers, notably John of Ephesus, tracked its progress across the Eastern Mediterranean, while writers in Western Mediterranean and Europe recorded various first pandemic plague outbreaks (John of Ephesus; Gregory of Tours, 4–5). Modern scholars have suggested uniformly destructive death tolls from Britain to Egypt with between 20 and 50% of the populating dying (Bratton 1981; Harper 2017; Mitchell 2015). Yet, the only epidemiological model ever attempted of a local outbreak, focused on Constantinople in 542, a city considered conducive to the spread of plague and where plague was thought to have claimed hundreds of thousands of lives, suggested a far lower death toll and that other outbreaks would have varied widely depending upon particular ecological and epidemiological conditions (White and Mordechai 2020).

While the plague undoubtedly caused significant deaths throughout the Mediterranean world, the assumption that it led to systemic changes is unsubstantiated. The high death toll and its assumed changes to social, economic, and cultural life depends largely on direct comparisons to the medieval Black Death (c. 1346–1352) and subsequent outbreaks during the Second Pandemic that continued in Europe until the early 19th century. The mere invocation of the word plague and its imaginative power, recently termed the 'Plague Concept', has created this assumption, overriding any suggestions that plague's impact might have been different in the sixth century than it was in the fourteenth or dependent upon local conditions (Eisenberg and Mordechai 2020). Plague effects are instead depicted as uniform across time and space. If the later sixth century Eastern Roman Empire witnessed social and economic problems, these issues cannot be causally linked to the first plague pandemic simply because it had the same pathogen as the second pandemic.

The immediate outbreak of Justinianic Plague led to certain economic challenges, but the Eastern Roman Empire was able to meet these problems within a few years. The plague had likely reached Constantinople via regular annual grain shipments from Egypt, which had been created to feed the city's population. These grain shipments had operated in some form for six hundred years. Due to somewhat frequent weather and other destabilizing conditions, the system had built in redundancies to ensure grain's timely arrival (Rickman 1980). The first few years after the arrival of the plague in Constantinople witnessed a drop in shipments likely due to a combination of demographic decline (death and migration) and economic stress. Yet, by the end of the 540s, the grain shipments had returned to their pre-plague numbers and showed no further evidence of strain (Zuckerman 2004: 16). The state was able to achieve such high priority objectives and ensure the smooth supply of food to its capital city to maintain social stability and state governance.

The Eastern Roman Empire did experience other short-term economic fluctuations in lower priority objectives. In the late 530s, the state had implemented a monetary reform of the bronze coins leading to an increase in their size, weight, and value (from 16 to 22 g.). However, by 543, these increases were reduced to levels below the reform, but still above what they had been earlier (20 g.), perhaps indicative of some economic stress. Yet, the coins would remain at this constant weight for the rest of Justinian's reign suggesting the state could meet economic demands after the initial shock of the plague outbreak. Several new laws have often been cited as attempting to deal with a reduction in taxes following the outbreak of plague, although how these changes reflected reality on the ground and how long they lasted is unknown (Sarris 2002; Meier 2016).

The state's ability to mitigate these plague consequences induced short-term effects that appear to have had no long-term impact on the state's existing military, political, and administrative goals. The re-conquest of Italy continued into the 550s, slowed down only by the need to fight a parallel war with the Persians in the East (Heather 2018). And it is worth noting that there were no known systemic changes to any other states around the Eurasian world including any of the successor states in the west or the Persian Empire in the east.

The plague also had little impact on long-term daily life across the Mediterranean world. Sixth century people, similar to anyone before the late nineteenth-century rise of germ theory and bacteriology, had no knowledge of what caused the plague outbreak, but they did try to mitigate its impact. During its initial phase in Constantinople, many people barricaded themselves inside their houses, which according to our sources sometimes worked, but could also lead to the death of entire households (*Procopius, Wars*, II. xxii-xxiii). Later on, elites, including the emperor himself, adopted the age-old response to epidemics of flight from urban to rural locations to prevent from getting sick. Indeed, sources often speak of entire abandoned villages, which is likely to have stemmed more from flight than catastrophic mortality (Theophanes AM 6053; Paul the Deacon 4, 14).

At a community level, religious rituals were introduced to stop the spread of plague, which contemporary sources suggested worked. The city of Clermont instituted a religious procession, for example, which purportedly stopped the plague from entering the city, as did the city of Rome (Gregory of Tours, 4. 5; 10. 1). We understand that religious responses do not stop the spread of diseases, but as we noted in the introductory paragraphs, from the perspective of medieval belief-systems this was entirely plausible, even if more obviously practical measures, from our point of view, were also adopted. The impact of the plague was not a one-size-fits-all catastrophe, but rather had varying effects across the Mediterranean world.

The inability to control environmental and systemic features of the sixth-century world compared to today's globalized world required the Roman state to build in far more redundancies (from our perspective inefficiencies) into their institutional structures. These redundancies allowed the Eastern Roman Empire to ensure the continuation of its fiscal and administrative structures with minor adjustments during the plague pandemic. Moreover, such infrastructural redundancies allowed the western successor states, who continued to use modified versions of the Roman imperial structures, the same flexibility. The economy may have been stressed during the initial outbreak in the 540s but returned to pre-outbreak levels by the end of the decade. Likewise, the monetary system may have been temporarily shocked, leading to an abandonment of an ambitious reform, but the long-term effects appear minimal. Wars were fought, taxes were raised, resources were allocated, and there were few direct changes to class relations. From a state resilience point of view, every contemporary state returned to its baseline macro socio-economic situation despite the short-term plague induced stress. If we discard the idea that plague must cause change simply because it is plague, then the effects of the Justinianic Plague do not appear significant beyond the local and short term.

14.5 Pandemics, 2: The Black Death

The Black Death, originating in Central Asia in the later 1330s, and ravaging Europe, the Middle East and North Africa between 1346 and 1353, is notorious for initiating the second known historical pandemic of *Y. pestis* and for spreading and killing millions. We lack the rich demographic data for the first two plague pandemics that we possess for recent or contemporary pandemics. For the second of the pandemics, however, we are in a much better place. Recent estimates have proposed that England lost about 50–60% of its population in just two years, with some densely populated regions experiencing even higher losses. Elsewhere in Western and Central Europe, as well as the Middle East and North Africa, population mortality seems to have been in the area of 50% or a bit higher.

All this, in turn, gives the impression that this was a catastrophe like no other, carrying far-reaching demographic and social implications over West Eurasia and North Africa, and possibly well beyond. To make things worse, the Black Death was followed by a series of recurrent outbreaks lasting centuries, beginning with the so-called *pestis secunda* of 1356–66 (Benedictow 2004; Arthur 2010; Slavin 2021 forthcoming). Alongside the immediate, felt, visible and short-term impacts, as reported by eyewitnesses, therefore, the Black Death also contributed to the speeding up of existing long-term trends, pushing some—but over several decades—to a crisis point that then led to substantial change.

Yet, when we examine how different states and societies responded to the Black Death, we find that—without minimizing the terrible impact on individuals, families and communities—the medieval world did not grind to a halt. For example, the Black Death struck at the beginning of the Hundred Years' War (1337–1453) between England and France (but involving most European polities), and in spite of its demographic impact both kingdoms continued to field effective armies, despite a brief pause in hostilities in the years 1348–1351. Quite remarkably, however, other hostilities—between England and Scotland, endemic warfare in the Aegean and eastern Mediterranean involving Genoa, Venice, the Byzantine Empire and the Turks, the kingdoms of Hungary and Naples, as well as ongoing conflict between the Kingdom of Castile and Emirate of Granada, including a struggle over Gibraltar (1349–50),—carried on even at the height of the outbreak. The business of fighting continued as usual. State structures continued to function with only minor adjustments (Goldstone 2010: 145; Balard 2008: 838–839, 850–851; Mantran and De La Roncière 1986: 365; Jackson 1896: 47–50).

Looking closer at the everyday experiences of commoners, we see little change. As local archival evidence from England (unusually rich in its volume and survival compared to other European lands) indicates, peasants continued their essential farming activities: they tilled, sowed and harvested as usual. Although the harvests of 1349 and 1350 were abysmally low (about 50 per cent below average), this was not only due to the shortage of people, but also to torrential rain that ruined both harvests. Given that England lost more than half of its population due to plague, the reduced harvest was just enough to meet the annual grain requirements of its population (Campbell 2015: 11 and 287–9).

In his famous *Decameron*, Giovanni Boccaccio, himself a survivor of the Black Death, lamented the breakdown of social morals and order. Yet, in reality, he was only half right: although the incidence of crime, and particularly violent crime, continued during the outbreak, as surviving documentation for some regions of Italy makes particularly clear, local authorities and their judicial institutions did their best to maintain order by apprehending and prosecuting felons—as evidence from Bologna indicates. Likewise, local court rolls from England show that local authorities acted upon accusations of various transgressions, ranging from dishonest baking and brewing to burglaries and violent attacks. The same court rolls also indicate that the land market was buoyant during the plague years, with tenants transferring and acquiring new parcels of land; these transactions were meticulously recorded by clerks, as in normal years. Moreover, the fact that we witness a sharp spike in the number of probated wills—all over Europe—demonstrates that both the public legal system (local courts) as well as private practitioners (notaries) continued to function without disruption during the pandemic (Dean 2015; Horrox 1994: 256–262, 321–322).

One unfortunate social manifestation of the Black Death was a rise in ethno-social scapegoating, resulting in the widespread persecution of minorities and marginalized groups: Jews, in particular. Between November 1348 and July 1350, in some 80 cities and towns in German-speaking areas of the Holy Roman Empire, Jewish communities were violently attacked and, in many instances, burnt to death. Irrational rumors of a Jewish conspiracy to destroy Christendom, via poisoning wells and spreading plague, diffused rapidly, even faster like the disease, taking roots in local communities in some instances a few months before the arrival of plague there. Although it is impossible to come up with secure estimates of deaths, it is clear that the Ashkenazi diaspora shrank considerably, as a result of both the plague and ongoing violence. Similar anti-Jewish pogroms took place in parts of Spain (particularly Catalonia), South France, the Low Countries (Hainault and Brabant) and some Italian cities, albeit on a much smaller scale (Haverkamp 2002: Cohn 2007). Anti-Jewish prejudice and violence was nothing new: if anything, the Black Death pogroms were an extreme physical (and horrifically augmented) manifestation of existing social and religious trends deeply embedded in late-medieval European societies.

If we want to find fundamental societal transformations triggered by the pandemic, we need to consider long- rather than short-term changes, and two developments in particular are worth comment. First, the breakdown of so-called 'feudal systems'. By extension this also entailed the erosion of serfdom—first and foremost, in England, where, again, documentation is the most dense, where sub-leasing for cash rents was on the increase along with manumission (acquisition of freedom for a one-off payment) was not a rare phenomenon, although about half of rural tenants still had servile status in the 1340s (Campbell 2005: 24–44). It is clear that the Black Death was a major catalyst in accelerating this ongoing process, together with a series of economic developments (such as a series of good harvests between ca. 1375 and 1400) that adversely affected landlords' manorial economies. The loss of at least 50 per cent of the population meant that the labour-to-land ratio fundamentally changed, with the sudden shortage of tenants to work on and occupy lords' land. Despite governmental intervention, fixing labourers' wages at their pre-plague level in 1349 and 1351, and the attempts of some lords to re-impose various feudal restrictions and customs, local tenants had an upper hand in bargaining and commanding higher wages and better terms of land rent. Between c.1350 and 1400, much of land tenure in England was transformed into customary 'copyholds' and 'leaseholds', while serfs and their family members were made 'free' tenants to ensure steady income from tenancy and working force on their demesnes. By c.1500, with the exception of a few 'conservative' exceptions (primarily in southern counties), the lion's share of English feudal demesnes was leased by and cultivated by better-off tenants. Centuries-old institutions of 'feudalism' and serfdom were largely gone.

In contrast, while serfdom was gradually eroding in Western Europe, it was rising in Europe east of the Elbe (from Brandenburg to Muscovite Russia). Here, local landlords managed to do what their western counterparts failed to do—impose their control over local peasantry. Grossly oversimplifying this complex process, whose particulars varied from region to region, we may still reduce its main causes to two main factors: institutional and monetary. Contrary to Western Europe, where English, French and Spanish monarchies reached a mature level of centralization, East European rulers were in the process of building centralized states. In doing so, they were relying upon the support of their nobles, which could be guaranteed in return for certain concessions. One such concession, coveted by local lords, was royal legislation aimed towards the enserfment of peasants, whereby the freedom of latter would be gradually limited. At the same time, there were serious inflations, when prices sky-rocketed, caused by both population growth and mostly by severe coinage debasements, especially in the course of the sixteenth and seventeenth centuries. This situation was precisely the opposite of what happened in England in the late fourteenth century: and under these circumstances of high prices and low production costs, it was profitable for local lords to exploit their demesnes directly, rather than leasing them to their tenants. This transformation laid down the foundations for economic backwardness in eastern Europe and the subsequent difficulties in catching up with the rest of Europe (Blum 1957; Hagen 1985).

A second major long-term transformation overlapping with the second plague pandemic was a discernable shift from a 'High Pressure Demographic System' (HPDS), dominated by high fertility, marriage rates and birth rates, and a larger proportion of younger people, to a 'Low Pressure Demographic System' (LPDS), dominated by low fertility, nuptiality and birth rates and a larger proportion of older people. In particular, the second wave of plague (the *pestis secunda* of 1356–66) had a huge influence on population demography, by killing the survivors of the Black Death and 'baby-boomers' born between the two outbreaks. With a low relative proportion of young people, Europe experienced a long-term demographic stagnation and decline, which persisted for some 100–150 years, and it was not until the late fifteenth and early sixteenth century that populations started growing. Thus, in England, between c.1390 and 1490, the population remained more or less static—around 2 million people—compared with some 5.25 million on the eve of the Black Death (Fig. 14.1).

In the case of North-Western Europe, England included, the demographic stagnation was exacerbated by the emergence of what John Hajnal and other sociologists call the 'European Marriage Pattern' ('EMP', even though 'North European Marriage Pattern' might be more appropriate). In a nutshell, the EMP is characterized by a relatively high age of first marriage for women (25–30) and a relatively high percentage of never-married women (10–25%)—not found in any other pre-Industrial historical civilization. While Hajnal himself placed the origins of the EMP in the sixteenth or seventeenth century, more recent studies locate it in the late-medieval period—perhaps as early as the late thirteenth century (that is, before the Black Death). But it was the Black Death that made EMP more widespread than ever before. In post-plague reality, more women had better economic and employment opportunity, as brewsters or domestic servants, and hence, more incentive to either delay their first marriage or choose not to marry at all (Hajnal 1965; Bennett 2015) (Fig. 14.1).

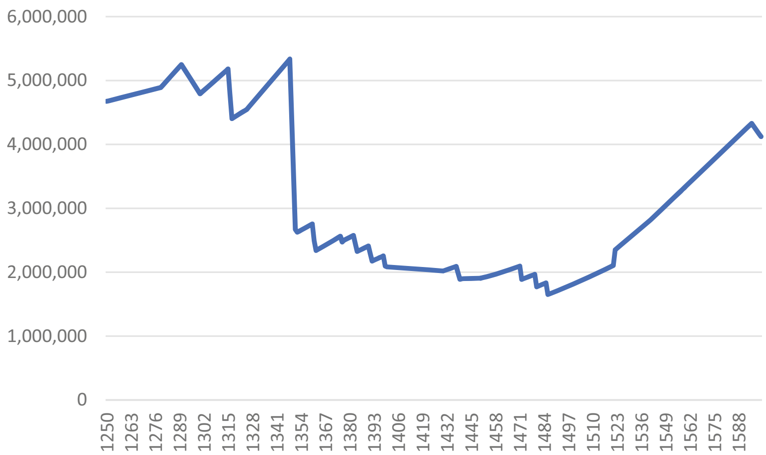

Fig. 14.1 English Population Movement Estimates, 1250–1600. *Source* Post-1377 figures derive from Broadberry et al. (2015): 10–30; pre-1377 figures recalculated on the basis of the benchmark of 5.25 million people in 1290, estimated in Slavin (2019): 18

The contours of society, both urban and rural, shifted considerably between the pre-Black Death and post-Black Death eras, but no single factor was the cause: fluctuating biological conditions (recurrent outbreaks of plague, harvests affecting grain prices), monetary factors (prices and wages), institutional aspects (shifts in tenurial arrangements and legal status of peasants), and demographic forces (emergence and perseverance of 'Low Pressure Demographic System' and 'European Marriage Pattern'), all played a contributory role. As we have emphasized above, the importance of the Black Death and its impacts is to be found in its contribution to the speeding up of existing long-term trends, pushing some—but over several decades—to a crisis point that then led to substantial change. When thinking about similar moments in the past or the present, it is the impact on the underlying structures of social and economic organization to which we need to pay attention.

14.6 Animal Epizootics

Livestock have been indispensable to human diet, economy and health for millennia and yet their health is vastly under-researched. In medieval Europe, before, during and after the plague pandemics, sheep clothed and kept many Europeans warm, while cattle were the primary trucks and tractors of agriculture and also the primary source of fertilizer, essential for the restoration of arable soils (Verhulst 2002: 66–68; Langdon 1986; Raepsaet 1997: 56–58; Campbell 2000: 123–127). Sheep and cattle were in addition relied upon for dairy, meat, hides and other byproducts. For meat, pigs were vital in many regions and periods. The centrality of cattle for grain farming and subsistence explains why medieval sources frequently report on epizootics, disease outbreaks, among bovines. Analyses of early medieval European texts, have identified 87 references pertaining to animal disease (Newfield 2013, 2015a; Renou, Beauval and Maury 2013; Putelat 2013). These passages refer overwhelmingly to cattle plagues, as about 80% mention the species; a more cursory survey of eleventh- through thirteenth-century European sources finds a similar trend (Newfield 2012a, 629–33). Although other domesticates undoubtedly suffered outbreaks of acute disease as well, it seems that those epizootics were either less noteworthy, of smaller scale, or simply had less of an impact on medieval life than cattle plagues. A few exceptions are nonetheless evident, such as the English ovine mortalities of 1279–80 and 1314–16 (Binois 2013; Binois-Roman 2017; Slavin 2015, 2016).

Regarding cattle, the medieval sources are abundant enough to identify and date large outbreaks of virulent disease that affected Europe on scales ranging from the regional to the continental (Kershaw 1973; Newfield 2009, 2012b; Campbell 2010a, b, 2011, 2015; Slavin 2012, 2015). Many of these outbreaks have been tentatively diagnosed as the rinderpest virus, a highly infectious disease that affected only cattle among common European livestock. With a fatality rate often surpassing 90% in the modern era, rinderpest could cause devastating losses in a short span of time (Barrett, Pastoret and Taylor 2006).

Whether or not rinderpest, as modern science recognizes it, was present in medieval Europe, it is clear that enormous quantities of animals did occasionally succumb to disease. For example, thanks to the survival of English manorial accounts, we know that when a major continental panzootic passed through parts of England in 1319–20 millions of cattle died (Campbell 2011: more than 500,000 working oxen died in England alone; Slavin 2012). Herd mortalities naturally varied, but the evidence demonstrates that many individual farms lost up to 100% of their bovines. Similar mortality rates can be assumed on the continent in that plague ($\sim$1315–18) and in earlier, less documented epizootics.

Epizootics could have devastating consequences for human societies. In medieval Europe and beyond (Mishra 2013; Newfield 2013, 2015b: White 2017), widespread loss of cattle in conjunction with other exacerbating factors is routinely tied to subsistence crises, outbreaks of human disease, and episodes of demographic contraction. But it is clear that medieval contemporaries employed a number of strategies to curb the spread of animal diseases and to limit losses. When these failed, a range of actions were also undertaken to recoup financial losses and rebuild herds in the wake of epizootics.

Evidence for these strategies predates the Common Era and persists throughout the medieval period into the modern. In anticipation of an animal plague's arrival, but also after an epizootic had irrupted, farmers could cull their animals to preserve (all or some of) the value of their meat (Slavin 2012). This could have been an effective measure for curbing the spread of animal diseases passed between live animals. Although diseased meat was undoubtedly eaten, possibly in good quantity after a cattle plague or if a cattle plague occurred in the context of a food shortage, it was hardly considered ideal (Newfield 2012a; Putelat 2013; Binois-Roman 2017): the bible forbids the consumption of such meat as carrion (Leviticus 22.8; Exodus 22.31; Deuteronomy 14.21) and most, if not all, early medieval penitentials imposed the prohibition (Bonnassie 1989), as did local 'public health' codes from the twelfth century onwards (Morot 1890). This said, medieval writers could relax restrictions on carrion consumption (Meens 1995; Ferrières 2006).

Once disease struck, sick animals were not simply left to die. Contemporaries made efforts to segregate healthy animals from visibly sick and dead ones, both when grazing and sheltered (Lommatzsch 1903; Newfield 2012a). This would have very likely proved efficacious as most livestock pathogens capable of causing large outbreaks of acute disease (e.g. rinderpest, contagious bovine pleuropneumonia) are spread primarily via direct contact between live animals. A variety of treatments were also employed, and if premodern interventions may not have worked against rinderpest, some of the steps taken to treat sick animals could have alleviated symptoms and animal distress (Slavin 2015). Stalls belonging to animals that succumbed to disease could be emptied and cleaned as well to preserve the health of other animals, and several written sources recommend or describe the deep burial of diseased carcasses in isolated places for the same reasons (Newfield 2012a, b; Renou et al. 2013; Binois-Roman 2017). Many sources, however, do make reference to carcasses being left to rot in the fields, which might have facilitated the spread of certain pathogens in a limited way (Newfield 2012a; Binois 2013; Binois-Roman 2017). The archaeological evidence relating to the disposal of diseased animals is naturally biased, as we now know only of those buried, but it appears to indicate a relatively low compliance with recommendations: most burials appear to answer to an economy of means, with animals interred in shallow pits near settlements (as at Téteghem, below) or repurposed structures (wells, latrines, ditches). In order to cut losses, many cattle and sheep were flayed before disposal, as specific visible cut-marks demonstrate and multiple medieval husbandry treatises recommended (Binois-Roman 2017). Meat removal, on the other hand, appears rare in archaeological burials. Most butchering traces can be linked to dismemberments carried out to squeeze animals into smaller pits (Putelat 2013; Binois-Roman 2017) (Fig. 14.2).

Naturally, restocking could be a long-term affair. Heifers gestate for ninth months, rarely deliver multiples and were uncommonly bred before their third year. Optimum milk production sets in around three years and raising (and training) a plough ox takes years. Further, animals surviving acute disease might not reproduce soon after recovery; and when sick, the expectant may abort. A theoretical model estimates that without further deaths and with perfect fertility, a 100-bovine herd which lost 85% in an epizootic would need 13 years to recover and close to 20 years if more probable 'medieval' bovine fertility and mortality rates are considered (Vallat 2009; Binois-Roman 2017). Sheep, with their shorter breeding cycle and higher prolificity, would in theory take less time to restock by relying on natural regeneration, though high mortality rates experienced in medieval flocks would have significantly slowed the process (Brumont 2005; Binois-Roman 2017). In non-pastoral regions without large cattle herds, recovery would have been more

Fig. 14.2 Mass sheep grave, Téteghem, Hauts-de-France, 13th Century. Photograph: Annelise Binois-Roman

arduous. In areas dotted with vaccaries, a pathogenic disease like rinderpest had more opportunity to spread, but recovery would have also been quicker (in cattle dense regions of recent Mongolia, for instance, some—but are certainly not all—herds have been replenished within five years of large weather-related mortalities—hard winters called *dzuds* (Soma and Schlecht 2018; Oniki and Dagys 2017)).

This said, few would have relied exclusively on natural regeneration to replenish their stock. In the same model herd, and assuming no additional deaths and perfect fertility, restocking takes nine years if the estate is able to buy five bovines anew each year (Vallat 2009). In the wake of the early-fourteenth-century panzootic, no less than four restocking strategies were employed (Slavin 2012, 2015). Animals from areas untouched by the disease were bought at market, animals were redistributed between associated manorial operations, animals were collected as dues, and animals were raised anew. Nevertheless, it is clear that the national seigniorial herd in England, as far as it can be reconstructed on the basis of surviving manorial accounts (which for the period of the panzootic concentrate in southern and eastern England), took more than two decades to attain its pre-panzootic level (about 1350). As for sheep, it took ten to 12 years to recover from significant losses in post-medieval Spain (Brumont 2005), and 14 years for the herds affected by the 1279–1280 epizootic to regain 80% of their pre-crisis levels, and no less than 33 years to fully recover (Slavin 2015). This said, it is clear that other mortality crises intervened in the restocking process and within the longer recovery stretches of relatively quick replenishment are visible. More than 80% of both seigniorial oxen and young cattle, and 90% of seigniorial mature and immature cattle, were replenished after the 1319 panzootic before 1331 and 1337 respectively (Slavin 2012). In other words, some farmers may have deliberately not brought their herds back up to early fourteenth-century levels. Decision making suited to particular, local contexts is clear from the source material that survives.

Peasants with fewer resources who lost their stock were at a higher risk and were more likely to experience arable contraction. Indeed, it is near certain large animal disease outbreaks would have exacerbated socioeconomic inequalities. Not only could lords restock more rapid, but some possessed or purchased horses to replace their draft cattle that died. In the wake of the 1319–21 English die-off, therefore, some wealthy seigniorial estates did not experience notable arable retraction (Slavin 2012). Elites possessed the means to make the best of the situation. At the same time, there are reports of peasants manually tilling their holdings and of lands lying bare (Newfield 2009); by 1323, an important surge in land sales by peasants is observable (Campbell 2010a, b). Clearly, some elites possessed the means to make the best of the situation.

Of course, in uncultivated land lied an opportunity. Following dramatic cattle mortalities, cohorts of other stock could be augmented and unused arable land given over to those animals. Greater numbers pigs, which are exceptionally prolific, and sheep could fill the void (this is visible again in English sources: Slavin 2012). But this too was more of an option for the wealthy. The appeal of this recalibration of stocking ratios may help to explain the slow and partial replenishment of cattle herds after the early fourteenth-century bovine panzootic.

That medieval cattle plagues seem not to have triggered subsistence crises on their own suggests adequate adaptive responses, particularly considering that cattle were then the draft animal *par excellence*. Five cattle plagues in the earliest medieval centuries do correlate in time and place to reported food shortages, but they also correlate with additional environmental stressors, often reported in the same texts. The causal pathway between these variables is difficult to disentangle. In short, animal plagues presented major challenges, especially large cattle die-offs, but medieval people possessed the means to mitigate, at least partially, and to cushion the impact of epizootics.

Thus far we have addressed the ways in which states and societies responded to and understood risks associated with relatively short-term and sudden, dramatic events, even if they had longer-term consequences—earthquakes, pandemics, epizootics. Climate changes are generally thought of as relatively longer-term, but they can also take place over quite short periods, and in the following we examine three examples of relatively rapid change and the responses to them. Combining the evidence from palaeoenvironmental research for changes in land-use and patterns of agricultural and livestock exploitation with the historical and the archaeological records can often give us a fairly clear indication of how societies responded in practical terms over the medium or longer term.

14.7 Climate, 1. Who Pays for the Survival of an Empire? The Byzantine 'Great Famine' (927–928 CE)

The role of elites and particular groups within elites is central to the resilience of 'states' themselves. Historically states have tended to be dominated—managed and administered—by members of a power-elite drawn from a socially privileged sector of society. Members of such groups are generally concerned as much with their own interests as they are with those of the state or ruler they serve, although some pre-modern states have been able to maintain, for a while, an establishment entirely divorced from the vested interests of their society. And it should be noted that this is a structural problem common to all pre-modern/pre-capitalist systems: states must rely on elites to maintain themselves, yet those elites, whatever their origins, also develop vested interests that compromise or jeopardize those of the state. The ways this relationship has worked itself out historically varied enormously. The problem remains today, of course, although 'elites' are generally both more complexly structured and sectorized (national, international and multinational), and state autonomy—and thus state economies—compromised by global economic factors: the interests of international finance and investment capital rarely overlap neatly with those of nation states, as variations in the markets, particularly during moments of global crisis, daily illustrate.

The Eastern Roman empire was undoubtedly one of the most sophisticated states in western Eurasia, with a complex and effective fiscal and administrative structure that maximized resource extraction and maintained a balance of power between the state, elites and provincial society. By the early tenth century, after two centuries of rebuilding after the shock of the early Islamic conquests (which entailed the loss of ⅔ of the state's territory and as much as ¾ of its fiscal revenues), it was entering a period of expansion in both the Balkans and the Middle East. In parallel, there had evolved a social elite of office holders and landowners who gradually achieved a near monopoly on the senior and middling posts in the military and civil administration. It was their task to implement government policy in the provinces, but their increasing wealth and status meant that by the tenth century they were also a potential source of opposition to the central government. The tension between these two aspects of the East Roman state revealed itself in the efforts of the elite to expand its wealth in land, generally at the expense of village communities who were a key element in the state's finances and provided the core of the provincial armies, thus jeopardizing the effectiveness of the central state administration itself.

In the 920s a series of natural disasters devastatingly impacted the agriculture of the western Anatolian provinces, giving the wealthy or powerful opportunities to absorb further properties into their estates (Kaplan 1992; Svoronos 1994; McGeer 2000; Morris 1976). In 927–28 CE there occurred a particularly severe winter in the Balkans and Anatolia, combined with a series of extremely poor reduced harvests. The result was later remembered (as was the disastrous famine that preceded the Black Death in northern Europe) as the 'Great Famine'. In contemporary descriptions of the resulting social crisis, legal sources distinguish between the 'powerful' (military and civil officials paid in gold coin by the central government and possessing liquid assets) and the 'weak' (peasant farmers and laborers whose livelihood and ability to pay their taxes depended on their harvest). The latter were forced into selling their land for food or money to survive. It is not surprising, therefore, that a subsistence crisis provided those with the necessary resources an opportunity to exchange liquid assets for large tracts of land.

To protect its own interests the state had to intervene through legislation that attempted to curb the increasing inequality. However, while also aimed at protecting the position of the economically most vulnerable, this legislation had only short-term success, chiefly because it was directed against the very people the state depended upon to implement it. Instead, the government was eventually forced to adopt—with only partial success—the tactics of the elite, converting public land into imperial estates in order to secure the income derived from them.

While the great famine of 927–28 did not create social change, it did accelerate it, as the Black Death, for example, later would. Its impact was twofold. It presented the better-off with an opportunity to exploit peasants whose livelihood had been destabilized by the severity of the winter; and they benefited from the fact that the state tried to secure its own survival by effectively seizing control itself of the private land of the free peasantry, who thus found themselves reduced to dependency either by the state that should have protected them or by those who sought to dispossess them. In the state's attempt to restrain its own elites, it destroyed the fortunes of the more vulnerable members of society.

14.8 Climate, 2. Who Pays for the Survival of an Empire?: The Ottoman State and the Limits of Resilience

The Ottoman Empire from the late sixteenth to early seventeenth centuries CE provides a good illustration of the limits to resilience in a pre-industrial society. Beginning from a small emirate in northwest Anatolia ca. 1300 CE, Ottoman rulers had by the 1550s expanded their territory to three continents covering 30 present-day countries and built an empire that drew on administratively and geographically diverse sources of income. A key factor in the empire's resilience was thus its size. It developed systems to mobilize crucial resources from distant locations to provision its cities and military and to balance regional surpluses and deficits, including food, labor, timber, and strategic materials (e.g. gunpowder). The security provided by Ottoman soldiers as well as legal and tax provisions encouraged the expansion of agriculture and the containment of mobile pastoralism. The empire seemed resilient to socio-environmental stress: when tested by a series of local droughts, shortages and famines during the 1560s–1580s, Ottoman officials were able to contain the damage by shifting tax burdens from the affected areas, ordering fixed-price sales of grain from other provinces, and in some cases arranging direct shipments from local or imperial granaries (White 2011; Mikhail 2011; Agoston 2004).

The Ottoman system of resource management could recover from small impacts, but multiple, continuous or repeated shocks pushed it towards breakdown, a situation that underlies the scale of crisis in the empire during the 1590s–1600s. This was a period of major crisis triggered by environmental and human stressors followed by a protracted and intermittent recovery, in terms of population, agricultural production, political stability and military power. Extended drought in central Anatolia in 1591–96 severely curtailed food output causing prices to double. Near-famine conditions developed in some regions. This coincided with a series of extraordinarily cold winters, a combination that caused a major epizootic outbreak affecting sheep and cattle across Anatolia, the Crimea, and the Balkans, eventually reaching Hungary and Central Europe. This massive death of livestock deprived rural producers of a major source of wealth and subsistence, and deprived Ottoman armies of a key source of protein (White 2017).

This was not, however, the only set of stress factors the empire faced, since it was at this time deeply enmeshed in the so-called Long War (1593–1607) with the Habsburg Empire. Therefore, instead of reducing taxation or providing relief supplies—the usual state response to droughts and famines—the state had to increase requisitions from the Balkan and Anatolian provinces that were the worst hit by escalating shortages and famines. This led to a major rural uprising, the so-called Celâlî Rebellion (1596–1610) (White 2011). The combination of famine, violence, population displacement and disease generated a significant mortality crisis in parts of the empire—tax records from the 1620s–40s suggest up to 50% mortality in many parts of Anatolia after the 1580s (Özel 2004, 2016)—all of which produced a situation that induced a long-term shift in Ottoman population and land use (Özel 2016; White 2011 and sources therein; Ocakoğlu et al. 2016).

The history of the late 1500s-early 1600s is a good illustration of how political complexity could constrain resilience in a situation where a combination of factors amplified the negative consequences of state activities, in this case a focus on revenue, provisioning, and military mobilization at the expense of diversification and risk reduction in during environmental stress. Lack of agricultural diversification in semi-arid regions, dependence on provinces near the imperial capital for extraordinary taxes and requisitions, lack of spare capacity in dealing with both simultaneous military and infrastructural emergencies, all stressed the system to capacity. These factors combined with difficulties of supplying and pacifying inland regions, poor overland communications and the interaction of famine, flight, insecurity, and disease. Together with inadequate public health systems that might mitigate epidemic disease impacts, the result was a severe and sustained population loss leading to an unstable balance between village agriculture and mobile pastoralism—and ultimately a fracturing of state management and control over provincial economies.

While the imperial system as a whole held together, the cost of the vulnerabilities inherent in the Ottoman system were borne disproportionately by the least privileged social groups. Just as in a markedly different context with the Eastern Roman Empire (the preceding case), this potentially undermined the resilience of the entire socio-economic and political system, since these groups formed the backbone of premodern economies. While the latter possessed a remarkable degree of resilience within the limits imposed by environmental and political conditions, when both acute social and environmental problems combined they could neither sustain their own livelihoods nor shoulder the burdens of imperial economies and ecologies.

14.9 Climate, 3: Early 19th-Century Krakow and the Costs of Sustainability

As with most of the Polish-Lithuanian Commonwealth—a ‘republican monarchy’ that ruled much of Central-Eastern Europe in the early modern period (16th-18th c. CE)—by the middle of the 18th century Krakow was slowly starting to recover from a generations-long crisis associated with frequent warfare that had torn Central Europe apart from the 1640s onward. As the former capital of the Commonwealth and one of its wealthiest cities, it had a rich urban infrastructure, hosted the oldest Eastern European university, and enjoyed an advantageous position on major European trade routes. In the final decade of the 18th century, the economic and demographic recovery slowed down, as the Commonwealth was conquered by its neighbors, Habsburg Austria, the Russian Empire and the Kingdom of Prussia. From 1795 Krakow became a provincial city on the northernmost periphery of the Habsburg monarchy.

This, however, was just one aspect of the challenges the city had to face in the late 18th c. We know from dendro-climatic reconstruction using dead and living larch trees from the nearby Tatra Mountains that, beginning in the 1780s and for several decades thereafter, the city experienced extremely cold spring seasons, one or two degrees colder than had been typical for the preceding half-century (Büntgen et al. 2013). The onset of this process was sudden and took place within a few years. Thanks to the daily measurements of weather conditions that started at the Jagiellonian University in Krakow in 1792 (and continue until today), it is clear that the coldest period of the year—from October to March—was unusually cold well until the 1830s. In the context of northern European climatic conditions, this means considerably increased energy requirements during the cold season—not only because of colder winters, but even more importantly due to the prolongation of the need for heating well into spring.

Fuel for heating and cooking was largely derived from local wood resources, and as Fig. 14.1 makes clear, the price of firewood in Krakow sky-rocketed as the annual spring temperatures started to fall. Paradoxically, the price situation improved after the city was conquered by Austria in 1795: the city’s deteriorating status led to a population decrease, reducing the demand for firewood, and at the same time the conquest provided the city with easier access to the timber-producing Carpathian highlands located to the south. Nevertheless, as the springs became even colder, the price trend persisted and firewood grew increasingly expensive.

Further pressure on firewood prices in Krakow occurred in the following decade. The Napoleonic wars affected this part of Europe economically in the period ca. 1805–1813, through extensive military operations, commercial blockades and related phenomena over several years. Under these conditions, firewood supplies were frequently cut off from the city by enemy military lines. Combined with the colder seasonal conditions in the winter and the spring, this created a major challenge for the city.

To resolve this situation, the inhabitants of Krakow introduced a major innovation and started to burn coal rather than wood, thus transitioning from the renewable resource of firewood and charcoal to the fossil fuel, coal. Easily accessible coal fields were located within 20–30 km of the city, and coal could be brought on carts relatively inexpensively, a practice hitherto largely avoided on a large scale due to the heavy smoke produced by burning coal rather than wood. By the 1810s average annual consumption of coal had already reached 2 tons per person, and this led to serious public health issues: official instructions on coal burning circulated by the city council leave no doubt that carbon monoxide poisoning became a significant problem. Over the following decades this early transition to fossil fuels, in a city located in a deep river valley with a significant number of days without wind, led to an accumulation of pollution which over generations led to a marked deterioration of the health of the urban and surrounding populations and a degradation of urban ecosystems (parks, gardens, urban woods, etc.). Krakow remains notorious for its poor air quality today (Izdebski and Wnek 2020).

This case of Krakow shows a vicious circle of socio-ecological maladaptation in the face of compounded environmental (climatic) and socio-economic (warfare) shock. In some respects, transitioning to fossil fuels was a significant adaptive innovation, drawing on local resources to solve an energy challenge. Yet the successful short-term technological adaptation led over the longer term to major environmental problems. It is arguable that Krakow's innovative early transition to fossil fuels—other Central European cities usually transitioned at least 60 years later—led in the end to much larger public health and environmental issues than had the city followed the standard path of Eastern European industrialization. This case study thus demonstrates two important aspects of social-ecological resilience. On the one hand, we need to consider the temporal scale: a quick-fix (in this case, technological and logistical) solution that allows the social-economic system (in this case, of a city) to continue its functioning for the following years, may undermine the long-term resilience of the same system. Therefore, looking at mere resilience and the ability to address social-ecological challenges is not enough and sustainability of the solutions being adopted should also be taken into consideration. Krakow's innovation was adaptive but unsustainable, and thus this case study shows that better planning and knowledge accumulation is necessary for finding solutions that would be sustainable in the long term (Fig. 14.3).

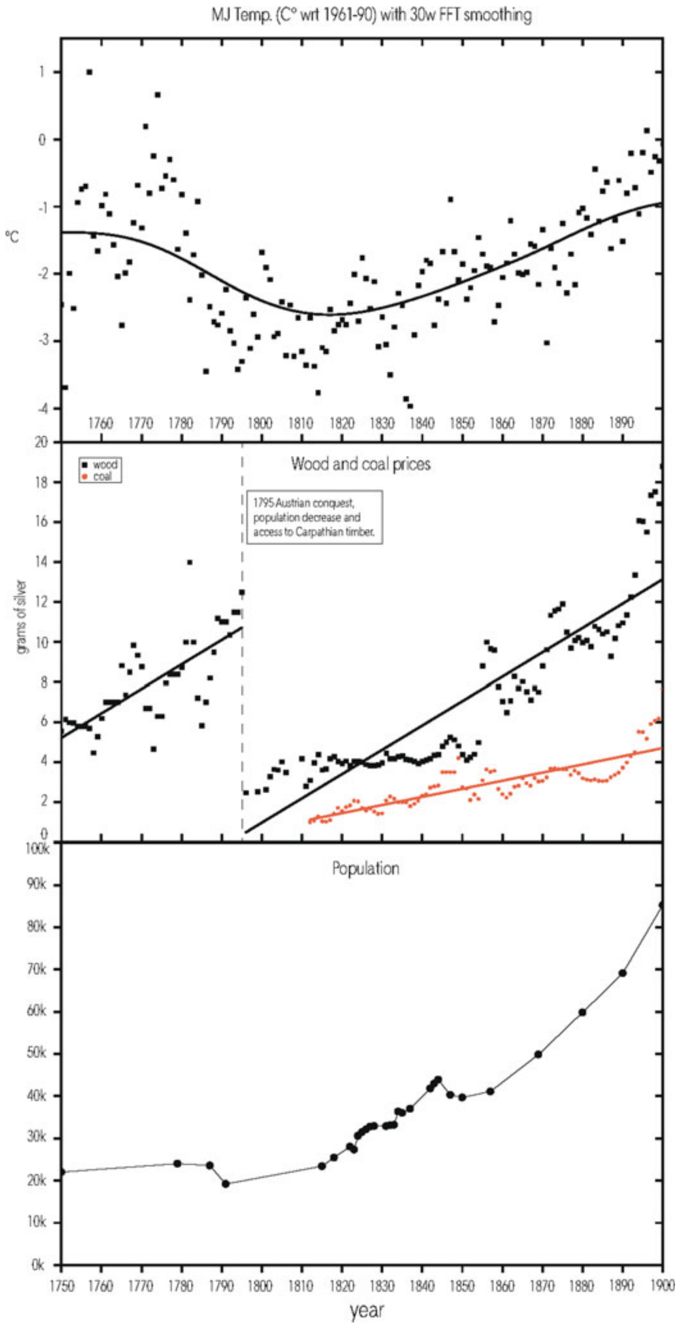

Fig. 14.3 Temperature, prices and population for Krakow 1750–1900 (https://www.pnas.org/content/110/5/1773)

14.10 Discussion

A number of conclusions or lessons can be drawn from our examples, all of which involved states or societies that were complex and possessed a degree of systemic redundancy, which is to say, overlapping institutional arrangements that in many instances could permit elements of one facet of social organization or state structure to fail without jeopardizing the system as a whole. The examples demonstrate that the costs of resilience were never shared evenly among the different components of these complex social systems. Resilience in one social group or institution—the rapid return of its baseline function, lifestyle and living conditions—influenced other groups within the same society. To understand the potential for all groups to receive just returns we must understand the connections between different social groups and their environments. One common thread seems clear: the underprivileged or less powerful have always been the most likely to bear the costs of societal resilience to environmental stress.

The examples illustrate the point that even where efforts were made consciously to assist a whole community—for example, in the case of the population of Krakow—the outcome could often generate unpredictable changes that could impact that community negatively. Not only do short-term strategies that sustain a state or a specific bundle of vested interests not necessarily promote longer-term societal resilience, they can also increase longer-term structural pressures leading to systemic crisis. To a degree, this applies also in the case of the Black Death in England, where the unforeseen longer-term result of the short-term responses was an increase in peasant social mobility and rural social diversity, facilitating a transformation of the labor market and social class relations. This forced the social elite to realign itself with new fiscal and market circumstances in order to protect its socio-economic dominance and at the same time inaugurated a longer-term challenge to its monopoly on local and central political office.

Nevertheless, there are cases where states possess sufficient systemic resilience to overcome very serious short-term challenges without further exacerbating existing inequalities, as the example of the Justinianic Plague suggests. Here, the imperial government readjusted quickly to provision food supplies for the population. Flexibility built into the imperial administration provided the empire with the capacity to manage a number of similar short term problems, from lower crop yields to catastrophic weather, which allowed the state to mitigate sudden changes to market supply. Such short-term responses secured the stability the state requited to meet its longer-term strategic aims as well as continuity of administration and government.

In the second place, the case studies illustrate the point that states, even where ostensibly ideologically predisposed to assist the poorest or weakest in society (e.g. the Christian Eastern Roman empire and the Islamic Ottoman empire) often resolved challenges by pushing the increased costs required for state survival onto those sectors of the society least able to resist—an inevitable consequence of pre-existing systemic inequalities. In the process, however, this also unintentionally transformed the relationships between the central power and central and regional elites. The great famine in the Eastern Roman empire that followed the severe winter of 927/8 CE tells exactly this story. Even though the imperial government legislated to protect the peasantry, its failure and subsequent adoption of the same economic strategies as those deployed by landlords and the landed elite began to jeopardize the state's access to fiscal resources. Along with the example of the catastrophic droughts suffered by the Ottomans in the 1590s CE, this illustrates how a central government unintentionally damaged its own economic base when the largest social group, the lower strata of society, lost much of its resilience to environmental stress and thus undermined the foundations of the state's fiscal economy. Lack of resilience on the part of the less privileged directly impacted the resources available to the state through taxes and requisitions, thus weakening the core functions of the central government, including the military.

In the third place, it seems clear that the greater the degree of baseline inequality at the outset of a crisis, the less resilience there is in the system as a whole, the more uneven the distribution of the resilience burden, and the greater the potential for post-solution breakdown of a given social order. Social elites, as identifiable groups, generally survive societal crises and transformations because they have a vested interest in preserving their position and often retain the resources to do so. In the wake of large animal disease outbreaks, for example, it is clear from the extant evidence that wealthy, landed populations recouped faster and, in some cases, were positioned to take advantage of the plight of their less wealthy neighbors. While individual members or sectors of elites may die or lose their positions of wealth and power, as a visible societal group they are often still around and at the top of the heap when the dust settles.

Naturally, there are exceptions: rapid revolutionary events such as in France between 1789 and 1794 or Russia in 1917–1918 can result in the effective removal of much of an established super-elite. But it is not uncommon for substantial elements of an established elite to adapt to radically changed circumstances and retain their basic socio-economic advantage, even where a major shift in political and ideological control takes place and these elites are no longer the ruling element. It was only very rarely that elites were effectively wiped out and replaced. There are many examples of elite survival throughout history: as with the middling elite of Sasanian Iran after the Islamic conquest in the 640s–650s (Pourshariati 2008; Morony 1984); it was true of the middling elites of the Western Roman Empire (Halsall 2007); it was true of local Balkan elites after the Ottoman conquests in the 14th–15th centuries CE (Kunt 1983; Inalcik 1973); it was just as true of traditional elites throughout the Middle East, Iran and as far as Afghanistan after Alexander's conquests in the 4th century BCE (Adams 2006; Erskine 2008).

Did people in the past think about system recovery? On a global scale, no. But, sectorally, as in the case of central governments with the means at their disposal, the answer varied: the degree of the problems they faced, the nature of economic and social class relationships, and, to some extent, the overall ideology and its key motifs were central factors. As a rule, the scope of recovery within a state or society was perceived as a goal but the focus was generally sectoral. Contemporaries rarely considered recovery at a global scale, and even then it was generally conceptualized and promoted within the purview of religion.

Did people understand the challenges and respond appropriately—or put another way, did social institutions possess the flexibility or resilience to adapt to challenges? The answer is not clear-cut. Representatives of religions tended to have a more global outlook (i.e. for people of the same faith), but their responses tended to be moral rather than practical (i.e. prayers to stop the calamity), and when they were practical they were inevitably local and short-term (i.e. famine relief, for example). Yet in both cases such responses could shore up solidarities and identities and thus contribute substantially to resilience. Ruling elites could respond, but they tended to react primarily to perceived threats to their own survival. This might well embrace the entire state, but as we have seen in some of the examples above, such responses were generally compromised by elite interests, as in the tenth-century medieval Eastern Roman empire. Furthermore, they usually were able to respond only to what they perceived as immediate problems—which may have been just symptoms of deeper issues. And were they able to implement policies to mitigate future risk? Yes, but again, for example in the case of tenth-century Byzantium or nineteenth-century Krakow, often with unforeseen consequences for the longer term.

14.11 Conclusions

We highlighted above three factors that combine and recombine in innumerable historical variations and that play a key role in determining how past social systems responded to stress: complexity (the degree of interdependency across social relationships and structures); systemic redundancy; and institutional and ideological flexibility. Together, these three factors determined the resilience of the system. Our examples illustrate different configurations that were the outcome of the way these combined in different historical circumstances. In some cases flexible responses to an immediate challenge generated short-term resilience but with heavier longer-term costs to a community as a whole (Krakow); in others, redundancies in system-wide processes enabled a longer-term flexibility that permitted continued system identity even as internal relationships transformed (zooepidemics, the Black death, 10th c. Byzantium); in yet others the accumulation of challenges began to overwhelm a hitherto relatively resilient system at certain levels, but not sufficient to bring about a general breakdown of the system (the Ottoman state in the 16th–17th c). The example of the Justinianic Plague remains a particular challenge in light of the dearth of exact demographic data or extensive archaeological evidence for its effects. But it also offers important data on how a system as a whole can maintain a degree of continuity while at the same time undergoing substantial transformative change at sub-systemic level. First we see the initial shock impact of a major pandemic on the city of Constantinople met by a series of emergency measures to maintain stability; then, during the following century or so, the longer-term consequences for cultural perceptions, including heightened levels of apocalyptic thinking; recurring outbreaks across the next two centuries and their impact on demography, labour availability and social structure; and the impact of these together with associated but exogenous factors (political unrest among the empire's neighbours, migratory pressures) on the empire's political military situation during the seventh century. The different paces and chronologies of sub-systemic change, the relatively high degree of systemic redundancy in administrative, economic and military capacities, all produced an outcome that permitted continued system identity, structural cohesion and reinforcement of centralised political authority in the face of substantial ideological opposition. The long-term cost was a substantial loss of territorial extent and relative economic power, a cost that may be seen as a simplification of the system as a whole, but a simplification that permitted a slow-burn transformation and thus improved systemic resilience.

Policy makers and political leaders today generally have a much greater appreciation of threats and risks, potential and actual—which puts them in a far better position to plan for system recovery. Just as in our historical cases, however, their ability to respond appropriately continues to be determined by a range of cultural/ideological, political/structural and economic factors, including elite interests, many of which work to constrain or even discourage the implementation of potentially effective policies that could address both short-term challenges and mitigate future risks. This becomes particularly acute when these elite interests do not align with those of the far more numerous non-elites, who are significantly more likely to be affected, as we have seen.

The tendency towards structural socio-economic imbalance in responses to environmental challenges must be a question that future policy planners place at the heart of their calculations. Because this sort of imbalance has generally been the case until now does not mean it has to be the case in the future—but in what circumstances this would *not* occur is an important, largely unanswered, and generally avoided question, except as a statement of general rhetoric. Ensuring a more equal and just distribution of the costs and thus extending resilience more evenly across all social-economic sectors would appear to be the obvious solution towards a more sustainable future for any complex socio-political system.

Acknowledgments SESYNC research is supported by funding received from the NSF DBI 1639145.

Disclaimer: This chapter is based, in part, on prior published research in the special issue on "Risk and resilience in the time of the COVID-19 crisis" (Igor Linkov and Benjamin D. Trump, editors) of Springer's Journal *Environment Systems and Decisions, v40(2), 2020.*

References

Abou Diwan G (2018) Base-metal coinage circulation in Byzantine Beirut 491–641 CE. Am J Numis 30:163–218

Adams WL (2006) The Hellenistic kingdoms. In: Bugh GR (ed.) The Cambridge companion to the Hellenistic world. Cambridge University Press, Cambridge, pp 28–51

Agathias. The Histories, Frendo JD (ed) Walter de Gruyter: Berlin and New York 1975
Agoston G (2004) Guns for the Sultan: technology, industry, and military power in the Ottoman empire. Cambridge/New York, CUP
Anderies JM (2006) Robustness, institutions, and large-scale change in social-ecological systems: The Hohokam of the Phoenix Basin. J Inst Econ 2/2:133–155
Arthur Paula (2010) The black death and mortality: a reassessment. In: Given-Wilson C (ed) Fourteenth century England VI. Boydell and Brewer, Woodbridge, pp 49–72
Balard M (2008) Latins in the Aegean (1300–1400). In: Shepard J (ed) The Cambridge history of the Byzantine Empire c. 500–1492. Cambridge, CUP, pp 834–851
Barrett T, Pastoret P-P, Taylor W (eds) (2006) Rinderpest and Peste des Petits Ruminants: Virus plagues of large and small Ruminants. Elsevier, Amsterdam
Bell C (2006) The evolution of long-distance trading relationships across the LBA/Iron Age transition on the northern Levantine coast: crisis, continuity and change. British Archaeological Reports, International series 1574. Archaeopress, Oxford
Benedictow OJ (2004) The black death, 1346–1353: the complete history. Woodbridge, Boydell and Brewer
Bennett JM (2015) Women and poverty: girls on their own in England before 1348. In: Kowaleski M, Langdon J, Schofield PR (eds) Peasants and lords in the medieval English economy. Essays in Honour of Bruce M. S. Campbell. Brepols, Turnhout, pp 299–324
Berkes F, Ross H (2016) Panarchy and community resilience: sustainability science and policy implications. Environ Sci Policy 61:185–193
Binois A (2013) Approche méthodologique des mortalités de masse ovines en archéologie. In: Auxiette G, Meniel P (eds) Les dépots d'ossements d'animaux en France, de la fouille à l'interprétation. Meniel, Montagnac, pp 275–286
Binois-Roman A (2017) L'archéologie des épizooties. Mise en évidence et diagnostic des crises de mortalité chez les animaux d'élevage du Néolithique à Pasteur. Université Paris I Panthéon-Sorbonne, Thèse de doctorat en archéologie environnementale
Bonnassie P (1989) Consommation d'aliments immondes et cannibalisme de survie dans l'Occident du Haut Moyen Âge. Annales ESC 44:1035–1056
Blum J (1957) The Rise of Serfdom in Eastern Europe. Am Hist Rev 62:807–36
Bratton TL (1981) The identity of the plague of Justinian. Trans Stud College of Physicians Phila 5 (3):113–124, 174–180
Broadberry S et al (2015) British economic growth, 1270–1870. CUP, Cambridge
Brumont F (2005) Les moutons de la grange de Quintanajuar en Vieille-Castille (1623-1834). In: Mousnier M (ed) Les Animaux Malades En Europe Occidentale (VIe-XIXe Siècle). Presses universitaires du Mirail, Toulouse, pp 117–124
Büntgen U, Myglan VS, Ljungqvist FC, McCormick M, Di Cosmo N, Sigl M, Jungclaus J, Wagner S, Krusic P J, Esper J, Kaplan JO, de Vaan MAC, Luterbacher J, Wacker L, Tegel W, Kirdyanov AV (2016) Eurasian cooling and societal change during the Late Antique Little Ice Age (536 to ~660 CE). Nat Geosci 9:231–236
Büntgen U, Kyncl T, Ginzler C et al (2013) Filling the Eastern European gap in millennium-long temperature reconstructions. PNAS 110:1773–1778
Campbell B (2010) Physical shocks, biological hazards, and human impacts: the crisis of the fourteenth century revisited. In: Cavaciocchi S (ed) Le interazioni fra economia a ambiente biologico nell'Europa preindustriale, secc. XIII–XVIII. Firenze University Press, Florence, pp 13–32
Campbell B (2015) The great transition: climate, disease and society in the late medieval world. CUP, Cambridge
Campbell B (2011) Panzootics, pandemics and climate anomalies in the fourteenth century. In: Herrmann B (ed) Beiträge zum Göttinger umwelthistorischen Kolloquium 2010–2011. Universitätsverlag Göttingen, Göttingen, pp 194–196
Campbell B (2010b) Nature as historical protagonist: environment and society in pre-industrial England. Econ History Rev 63:288–291
Campbell B (2005) The agrarian problem in the early fourteenth century. Past Present 188:3–70

Campbell B (2000) English seigniorial agriculture, 1250–1450. CUP, Cambridge
Cohn SK Jr (2007) The Black Death and the burning of Jews. Past Present 196:3–36
Cumming GS, Peterson GD (2017) Unifying research on social–ecological resilience and collapse. Trends Ecol Evol 32:695–713
Dark K (2016) The waves of time. Long-term change and international relations. London-New York, Bloomsbury
Dean T (2015) Plague and crime: Bologna, 1348–1351. Contin Change 30:367–393
Eisenberg M, Mordechai L (2020) The Justinianic plague and global pandemics: the making of the plague concept. Am Hist Rev 124(5):1632–1667
Elias A, Tapponnier P, Singh SC, King GCP, Briais A, Daëron M, Carton H et al (2007) Active thrusting offshore Mount Lebanon: source of the Tsunamigenic A.D. 551 Beirut-Tripoli Earthquake. Geology 35(8):755–58
Erskine A (2008) A companion to the hellenistic world. Blackwell, Oxford-Malden MA
Ferrières M (2006) Sacrad cow, mad cow: a history of food fears. Columbia University Press, New York
Goldstone J, Haldon JF (2009) Ancient states, empires and exploitation: problems and perspectives. In: Morris I, Scheidel W (eds) The dynamics of ancient empires. State power from Assyria to Byzantium. Oxford UP, Oxford, pp 3–29
Goldstone N (2010) Joanna: The Notorious Queen of Naples, Jerusalem and Sicily. Weidenfeld & Nicholson, London
Gregory of Tours: Krusch B, Levison W (eds) (1937) Gregorii episcopi Turonensis Historiarum libri X., Monumenta Germaniae historica, Scriptorum rerum Merovingicarum I. Hahn, Hannover
Gunderson Lance H, Holling CS (eds) (2002) Panarchy: understanding transformations in human and natural systems. Island Press, Washington DC
Hagen WW (1985) How Mighty the Junkers? Peasant rents and seigneurial profits in sixteenth-century Brandenburg. Past Present 108:80–116
Hajnal J (1965) European marriage pattern in historical perspective. In: Glass DV, Eversley DEC (eds) Population in history. Arnold, London, pp 101–143
Haldon JF, Chase AF, Eastwood W, Medina-Elizalde M, Izdebski A Ludlow F, Middleton G, Mordechai L, Nesbitt J, Turner BL (2020) Demystifying collapse: climate, environment, and social agency in pre-modern societies. Millennium 17:1–33
Haldon JF, Rosen AM (2018) Society and environment in the East Mediterranean ca 300–1800 CE. Problems of resilience, adaptation and transformation. Human Ecol 46(3):275–290
Hall LJ (2004) Roman Berytus: Beirut in Late Antiquity. Routledge, London and New York
Halsall G (2007) Barbarian migrations and the Roman West, 376–568, Cambridge medieval textbooks. CUP, Cambridge
Harper K (2017) The fate of Rome. Climate, disease, and the end of an empire. Princeton University Press, Princeton/Oxford
Haverkamp A (2002) Zur Chronologie der Verfolgungen zur Zeit des “Schwarzen Todes”. In: Haverkamp A (ed) Geschichte der Juden im Mittelalter von der Nordsee bis zu den Südalpen, kommentiertes Kartenwerk, 3 vols. (Hahnsche Buchhandlung: Hannover, vol. i: 223–242)
Heather P (2018) Rome resurgent: war and empire in the age of Justinian. OUP, New York
Heather P (2005) The fall of the Roman Empire. Macmillan, London
Holling CS (2001) Understanding the complexity of economic, ecological, and social systems. Ecosystems 4(5):390–405
Horrox R (1994) (ed and trans) The Black Death. Manchester University Press, Manchester
Inalcik H (1973) The Ottoman Empire: the classical age, 1300–1600. Praeger, New York
Izdebski A, Wnęk K (2020) The history of Krakow smog. In Izdebski A, Szmytka R (eds) Krakow. An ecobiography. Pittsburgh University Press, Pittsburgh
Jackson WGF (1896) The rock of the Gibraltarians. Associated University Presses, Cranbury NJ
Jennings S (2004–2005) Vessel glass from Beirut: BEY 006, 007 and 045. Berytus 48–49
John of Ephesus, in Witold Witakowski, Pseudo-Dionysius of Tel-Mahre. Chronicle, Part III. Liverpool University Press, Liverpool 1996

Kaplan M (1992) Les hommes et la terre à Byzance du VIe au XIe siècle: propriété et exploitation du sol. Publications de la Sorbonne, Paris
Kennedy H (1985) From Polis to Madina: urban change in late antique and early Islamic Syria. Past and Present 106:3–27
Kunt I Metin (1983) The Sultan's Servants: the transformation of Ottoman Provincial Government 1550–1650. Columbia University Press, New York
Langdon J (1986) Horses, oxen and technological innovation: the use of draught animals in English farming from 1066 to 1500. CUP, Cambridge
Lommatzsch E (ed) (1903) Digestorum Artis Mulomedicinae Libri. Publisher, Teubner, Leipzig
Mantran R, De La Roncière C (1986) Africa opens up to the old worlds. In: Fossier R (ed) The Cambridge illustrated history of the middle ages III. 125–1520. CUP, Cambridge, pp 356–395
McGeer E (2000) The land legislation of the Macedonian emperors. Pontifical Institute of Mediaeval Studies, Toronto
Meens R (1995) Pollution in the early middle ages: the case of the food regulations in Penitentials. Early Mediev Eur 4:3–19
Meier M (2016) 'The "Justinianic Plague": the economic consequences of the pandemic in the eastern Roman empire and its cultural and religious effects. Early Mediev Eur 24:267–292
Mikhail A (2011) Nature and empire in Ottoman Egypt. Cambridge/New York, CUP
Mikati R, Perring D (2006) Metropolis to Ribat: some recent work on Beirut at the end of antiquity. ArchaS. *2011.* 'ology History Lebanon 23:42–55
Mishra S (2013) Cattle, dearth, and the colonial state: famines and livestock in Colonial India, 1896–1900. J Soc History 46:989–1012
Mitchell S (2015) A history of the later Roman empire, AD 284–641, 2nd edn. Chichester, Wiley Blackwell
Mordechai L (2020) Berytus and the aftermath of the 551 earthquake. Late Antiquity Stud Sour Crit 17–18:197–241
Mordechai L et al (2020) Quantitative analysis and plagued assumptions: a response to Mischa Meier. Medizinhistorisches J 55(3):290–293. https://doi.org/10.25162/mhj-2020-0011
Morony M (1984) Iraq after the Muslim conquest. Princeton University Press, Princeton
Morot C (1890) De la réglementation du commerce des viandes de boucherie du XIIe au XVIe siècle. Typographie, Lithographie a Maulde, Paris
Morris R (1976) The powerful and the poor in tenth-century Byzantium: law and reality. Past and Present 73:3–27
Newfield T (2015a) Human-Bovine Plagues in the early Middle Ages. J Interdiscip History 46:1–38
Newfield T (2015b) Domesticates, disease and climate in early post-classical Europe: the Cattle Plague of c.940 and its environmental context. Postclass Archaeol 5:95–126
Newfield T (2013) Early Medieval epizootics and landscapes of disease: The origins and triggers of European Livestock Pestilences, 400–1000 CE. In: Kleingärtner S et al (eds) Landscapes and societies in Medieval Europe East of the Elbe: interactions between environmental settings and cultural transformations. Pontif Instit Mediev Stud, Toronto, pp 73–113
Newfield T (2012a) Epizootics and the consumption of diseased meat in the Middle Ages. In: Ammannati F (ed) Religione e Istituzioni Religiose Nell'Economia Europea, 1000–1800. Firenze, pp 629–633
Newfield T (2012b) A Great Carolingian Panzootic: the probable extent, diagnosis and impact of an early ninth-century Cattle Pestilence. Argos 46:200–212
Newfield T (2009) A cattle panzootic in early fourteenth-century Europe. Agricultural History Review 57:155–190
Ocakoğlu F, Oybak Dönmez E, Akbulut A, Tunoğlu C, Kır O, Açıkalın S, Erayık C, Ömer Yılmaz İ, Leroy SAG (2016) A 2800-year multi-proxy sedimentary record of climate change from lake Çubuk (Göynük, Bolu, NW Anatolia). The Holocene 26:205–21
Oniki S, Dagys K (2017) Recovery from a winter disaster in Töv Province of Mongolia. J Arid Environ 139:49–57

Özel O (2004) Population changes in Ottoman Anatolia during the 16th and 17th centuries: the 'demographic crisis' reconsidered. Int J Middle East Stud 36:183–205

Özel O (2016) The collapse of rural order in Ottoman Anatolia: Amasya 1576–1643. Leiden, Brill

Paul the Deacon, Historia Langobardorum. In: Bethmann H, Waitz G (eds) Monumenta Germaniae Historica, Script. rer. Langobardorum 12. Hanover 1878

Piacenza Pilgrim. Antoninus Placentinus. In: Geyer P (1898) Itinera Hierosolymitana 39:157–218. Corpus Scriptorum Ecclesiasticorum Latinorum. Tempsky, Vienna

Pirazzoli PA (1986) The early Byzantine tectonic paroxysm. Zeitschrift für Geomorphologie 62:31–49

Pirazzoli PA, Laborel J, Stiros SC Earthquake clustering in the eastern Mediterranean during historical times. J Geophys Res Solid Earth 101(B3):6083–6097. https://doi.org/10.1029/95JB00914

Pourshariati P (2008.) Decline and fall of the Sasanian empire. The Sasanian-Parthian confederacy and the Islamic conquest of Iran. I.B. Tauris, New York, London

Procopius, Wars. In: Dewing HB (1914) Procopius, Works. Loeb Classical Library, vols 1–5. Macmillan, London and New York

Procopius, Secret History. In: Dewing HB (1914) Procopius, works. Loeb classical library, vol 6. Macmillan, London and New York

Ps. Dionysius of Tel-Mahre. The Chronicle of Zuqnīn Parts III and IV A.D. 488–775 Harrak A (ed) (1999) Mediaeval Sources in Translation 36. Pontifical Institute of Mediaeval Studies, Toronto

Putelat O (2013) Archéologie des dépots animaux et mortalité extraordinaire du cheptel bovin au premier Moyen Âge: Plaidoyer pour une redynamisation et une mise en perspective de la recherche. Auxiette and Meniel 2013:249–274

Raepsaet G (1997) The development of farming implements between the Seine and the Rhine from the second to the twelfth century. In: Astill G, Langdon J (eds) Medieval farming and technology: the impact of agricultural change in Northwest Europe. Brill, Leiden

Renou S, Beauval C, Maury M (2013) Un bilan des connaissances sur les epizooties au Moyen Âge et un episode de mort extraordinaire de bovines à Luxé (Charente) durant l'époque mérovingienne. Auxiette and Meniel 2013:133–143

Reynolds P, Waksman Y (2007) Beirut cooking wares, 2nd to 7th centuries: local forms and North Palestinian imports. Berytus 50:59–81

Reynolds P (2000) The Beirut Amphora type, 1st century BC-7th century AD: an outline of its formal development and some preliminary observations of regional economic trends. Rei Cretariae Romanae Favtorum Acta 36:387–95

Rickman Geoffrey E (1980) The Grain trade under the Roman Empire. Mem Am Acad Rome 36:261–275. https://doi.org/10.2307/4238709

Rosen AM (2007) Civilizing climate: social responses to climate change in the ancient Near East. Rowman Altamira, Lanham, MD

Saghieh-Beydoun M (2004) Evidence for earthquakes in the current excavations of Beirut City centre. In: Doumet-Serhal C (ed) Decade: a decade of archaeology and history in the Lebanon. The Lebanese British Friends of the National Museum, Beirut, pp 280–85

Sarris P (2006) Economy and society in the age of Justinian. CUP, Cambridge

Sarris P (2002) The Justinianic plague: origins and effects. Contin Change 17:169–182

Sherrat S (2003) The Mediterranean economy: "Globalization" at the end of the second millennium B.C.E. In: Dever WG, Gitin S (eds) Symbiosis, symbolism and the power of the past: Canaan, ancient Israel, and their neighbors from the Late Bronze Sage through Roman Palaestina. Proceedings of the centennial symposium W.F. Albright Institute of Archaeological research and American Schools of Oriental Research, Jerusalem, May 29–31, 2000. Eisenbrauns, Winona Lake, Ind, pp 37–54

Slavin P (2021) (forthcoming) Out of the West: formation of a permanent plague reservoir in South-Central Germany (1349–1356) and its implications. Past Present

Slavin P (2019) Experiencing famine in fourteenth-century Britain. Turnhout, Brepols

Slavin P (2016) Epizootic landscapes: Sheep Scab and regional environment in England in 1279–1280. Landscapes 17:156–170
Slavin P (2015) Flogging a dead cow: coping with animal panzootic on the eve of the Black Death. In: Brown A, Burn A, Doherty R (eds) Crises in economic and social history: a comparative perspective. Boydell Press, Woodbridge, pp 111–137
Slavin P (2012) The Great Bovine Pestilence and its economic and environmental consequences in England and Wales, 1318–50. Econ History Rev 65:1239–1266
Soma T, Schlecht E (2018) The relevance of herders' local ecological knowledge on coping with livestock losses during harsh winters in Western Mongolia. Pastor Res Policy Pract 8:3
Stone D (2005) Decision-making in medieval agriculture. OUP, Oxford
Svoronos N (1994) Les Novelles des empereurs macédoniens concernant la terre et les stratiotes. Centre de recherches byzantines, Athens
Theophanes the Confessor, Chronographia, de Boor C (ed), Leipzig 1883–85
Vallat F (2009) Les Bœufs malades de la peste, la peste bovine en France et en Europe. Presses universitaires de Rennes, Rennes, XVIIIe-XIXe siècle
Verhulst A (2002) The Carolingian economy. CUP, Cambridge
Waksman Y, Reynolds P, Bien S, Tréglia J-C (2005) A major production of late Roman 'Levantine' and 'Cypriot' common wares. In: Gurt i Esparraguera JM. Buxeda i Garrigós J, Ontiveros MAC (2005) LRCW I: Late Roman Coarse Wares, Cooking Wares and Amphorae in the Mediterranean: Archaeology and Archaeometry. BAR International Series 1340. Archaeopress, Oxford, pp 311–25
Walker B, Holling CS, Carpenter SR, Kinzig A (2004) Resilience, adaptability and transformability in social–ecological systems. Ecol Soc 9(2):5–13
White LA, Mordechai L (2020) Modeling the Justinianic Plague: comparing hypothesized transmission routes. PLoS ONE 15:
White S (2011) The climate of rebellion in the early modern Ottoman empire. Cambridge/New York, CUP
White S (2017) A model disaster: from the great Ottoman panzootic to the cattle plagues of early modern Europe. In: Varlık N (ed) Plague and contagion in the Islamic Mediterranean: new histories of disease in Ottoman society. Medieval Institute Publications/Arc Humanities Press, Kalamazoo, pp 91–116
Zuckerman C (2004) Du village à l'empire: autour du registre fiscal d'Aphroditô (525/526). Centre de recherche d'histoire et civilisation de Byzance. Monographies 16. Association des amis du centre d'histoire et civilisation de Byzance, Paris

Chapter 15
COVID and Climate: Exploring Categorical Resilience in the Built Environment

Jesse M. Keenan

Abstract This chapter provides a perspective on the parallels between resilience activities associated with climate change and the ongoing COVID responses in the U.S. Through the lens of the built environment, this chapter provides selected insights into how various disaster, organizational, and engineering resilience activities have likely positively shaped COVID responses within the healthcare sector. These reciprocal influences are contextualized within extensive efforts within public health and healthcare management to calibrate community resilience frameworks and practices for utilization in everything from advancing community health to the continuity of health care facilities and operations. Thereafter, the chapter shifts focus to speculate on how ongoing experiences under COVID might yield positive impacts for future resilience designs, plans and policies within housing and the built environment. The chapter concludes with a discussion on the theoretical limitations of resilience that are further exposed by the dual and concurrent challenges of climate change and COVID. In particular, limitations to social learning and adaptive capacity for multilateral communication intelligence are explored as future avenues for resilience development. Through this perspective, the chapter hopes to highlight those often overlooked aspects of the physical and social parameters of the built environment that may be understood as providing opportunities to inform future disaster, public health, and climate change preparations and responses.

Keywords COVID-19 · Resilience · Disaster resilience · Community resilience · Built environment · Housing

---

J. M. Keenan (✉)
School of Architecture, Tulane University, New Orleans, USA
e-mail: jkeenan@tulane.edu

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_15

15.1 Introduction

The parallel occurrence of accelerated climate change impacts and a pandemic, such as COVID-19 ("COVID"), have long been within the realm of plausibility. Yet, in popular terms, even among emergency managers and policymakers, this was largely relegated to the *unthinkable*. Like climate change, the COVID (SARs) pandemic was widely anticipated among public health officials and medical scientists for decades (Kleinman and Watson 2006; Yang et al. 2020). Among climate change experts, the risks of infectious disease and pandemics have long been on the list of multi-hazards to anticipate (Semenza and Menne 2009) and to observe (Caminade et al. 2019). Indeed, some of the planning associated with the next anticipated SARs pandemic has laid the foundation for ongoing treatment and vaccine coordination happening on a global scale. Yet, for the most part, the risks and consequences from any number of potential—and even likely—pandemics have been broadly ignored by the general public and policy makers for decades—despite the certainty of the science and despite the warnings by global health organizations. This failure of action reflects long observed policy failures associated with a lack of precautionary principles, as well the behavioral and cognitive limitations to assess, respond and prepare for a rank of risks and impacts (Sunstein 2006). Yet, the unpredictable nature of these perils across social and environmental systems limits not only an assessment of potential and ongoing exposure, but it also limits the parameters of responsible institutions that define society's adaptive capacity for both autonomous and planned adaptation, including designed resilience.

This chapter provides a perspective on the parallels between resilience activities associated with climate change and other systematic risks and the ongoing COVID responses in the U.S. Through the lens of the built environment, this chapter provides selected insights into how various disaster, organizational, and engineering resilience activities have likely positively shaped COVID responses within the healthcare sector. These reciprocal influences are contextualized within extensive efforts within public health and healthcare management to calibrate community resilience frameworks and practices for utilization in everything from advancing community health to the continuity of health care facilities and operations. Thereafter, the chapter shifts focus to speculate on how ongoing experiences under COVID might yield positive impacts for future resilience designs, plans and policies within housing and the built environment. The chapter concludes with a discussion on the theoretical limitations of resilience that are further exposed by the dual and concurrent challenges of climate change and COVID. In particular, limitations to social learning and adaptive capacity for multilateral communication intelligence are explored as future avenues for resilience development. Through this perspective, the chapter hopes to highlight those often overlooked aspects of the physical and social parameters of the built environment that may be understood as providing opportunities to inform future disaster, public health, and climate change preparations and responses.

15.2 Resilience Planning Informs COVID Response

Among the categorical variants of resilience, it is disaster and engineering resilience that are most widely utilized in the U.S. (Keenan 2018a). While advancements in the framing and measurement of community resilience have been popular in the literature as a free-standing largely normative exercise, in practice, much of this work has operated to provide a social and human dimension to the operations of disaster resilience among emergency management institutions (NIST 2015). While there are known limitations to emergency management's ability to challenge long-term vulnerabilities defined by locked-in institutions (Gillard 2016), COVID is the type of shock that fits within emergency management's multi-hazard framework (Djalante et al. 2020). In the past decade, multi-hazard disaster resilience planning has had significant impacts in shaping the design and management of the built environment in everything from supporting the business continuity of private enterprise (Keenan 2015) to the sustainable provision of critical public services (Humphries 2019).

Over the past decade, public health officials have actively participated in the diffusion of disaster resilience planning practices alongside their colleagues in emergency management, urban planning, and civil engineering. While mass casualty preparations in recent years in the U.S. have largely centered on human-centered violence under a different policy regime within homeland security in the age of terrorism and mass shootings, disaster resilience planning activities have engaged both public and private health systems to look inward in terms of internal communications and business continuity; critical facilities and operations assessments; and multi-network contingency planning (Zhong et al. 2014; Verheul and Dückers 2020). The urgency of this work was well amplified with the high-profile loss and evacuation of NYU Langone Medical Center in New York City during Hurricane Sandy in 2012—a major center of healthcare for much of Manhattan (Powell et al. 2012; Seltenrich 2018). In the years that followed, healthcare systems from across the country have been actively preparing for a variety of hazards, including those associated with climate change impacts (USCRT 2016). By the time Hurricane Harvey hit Houston in 2017, the sector had a new champion in the Texas Medical Center, which has served as the quintessential case study for engineering and operational resilience capacities (Flynn 2018). It is worth recognizing that the motivation for such resilience investments is partially driven by the potential for superior health outcomes, but it is also a function of the economic losses that resonate well beyond facilities repair and replacement (Desai et al. 2019).

Disaster resilience models and techniques have informed nearly every aspect of facilities design and management from dry flood proofing of critical equipment to real-time intelligence of surface transportation for managing vehicle traffic. Beyond facilities, healthcare firms have also benefited from organizational resilience efforts to prepare for alternative supply chains and procurements models (Mandal 2017). But, disaster resilience 'thinking' also forced hospital and healthcare networks to evaluate the adaptive capacity of their building designs to handle multiple types of programs and alternative configurations (Aghapour et al. 2019). We see the benefits of this today with the physical expansion of intensive care units ("ICU") into other parts of hospital facilities, as well as the coordination between in-hospital care and the utilization of portable mass care facilities. By another measure, the rapid deployment of telemedicine may very well challenge the future utility of some medical facilities, even if that ultimately means something like smaller waiting rooms in family practice offices (AlDossary et al. 2017). In the broader national effort to cut healthcare costs, every square foot counts. Telemedicine may also be accelerated by a broader push for the digitalization of records and the documentation of patient care and billing—potentially automated processes. In addition, as healthcare networks have expanded into a hub and spoke model for outpatient care, these outpatient facilities have turned into what used to be the purpose of neighborhood public health facilities—they have become, in some cases, a critical access points for COVID testing and triaging (Elrod and Fortenberry 2017). In some cases, a commercial pharmacies such as CVS and Wallgreens are doing what a county public health facility used to do, in terms of offering access to primary health screening and point-of-service access.

While a replacement of public health facilities with private healthcare facilities is not a particularly defensible model, this ad hoc utilization amplifies the proposition of several U.S. cities, including Miami, for the development of local 'resilience hubs' that can serve as a physical platform for deploying public health, food, information and other resources for communities in good times and in bad (City of Miami 2020). Unfortunately, such 'hubs' are not currently considered critical facilities under U.S. Department of Homeland Security ("DHS") rules and are therefore ineligible for funding under a number of programs. Perhaps moving forward, reinvestment in community public health facilities through DHS programs could serve a variety of public health and disaster and community resilience co-benefits. Indeed, public health scholars and practitioners have made considerable advances in operationalizing community resilience in a manner that provides a compelling bottom-line economic business case for the value of these types of investments.

In a post-Cutter landscape of indeterminate quantitative socioeconomic resilience indicators (Burton 2015) that are limited in their replicability and scalability within existing policy pathways (Cutter and Derakhshan 2019), public health has stepped-up to advance a mix of quantitative and qualitative community resilience indicators that tell a broader story of community health that is central to our physical and mental capacity to endure climate change and other public health crises (WHO 2018). Indeed, public health has squarely captured the attention of public policy makers by arguing that community resilience is central to offsetting existing inequitable disparities in accessing the U.S. healthcare system (Lichtveld 2018). But, these advancements have come in all sorts of shapes and sizes. At a truly community scale, there is little doubt that community gardens started by public health and civic ecology advocates in the name of community resilience will be providing fresh, healthy food for families struggling with COVID this summer

(Shimpo et al. 2019). Cooling centers have been pioneered this type of thinking, but are clean-air centers the next necessity in California during fire seasons? Perhaps community gardens and resilience hubs should both be added to the DHS critical facilities list—along with pharmacies, grocery stores, clean-air, cooling and other facilities that are truly critical for social welfare and life-safety.

15.3 COVID Informs Future Resilience Planning

Aside from an expanded list of critical facilities, the COVID crisis offers insights into a variety of vulnerabilities, coping strategies, and an ad hoc interventions that offer insight into future resilience planning and design activities. It is widely acknowledge that resilience is generally advanced in institutional terms each time that a government or a community has an experience with a disaster—there is always something to be learned (Young 2010; Henly-Shepard et al. 2015). The goal is to minimize the cost of that learning. Another recent disaster—the foreclosure crisis (2008–2011) during the Great Recession—led to a number of legislative reforms that identified financial risks at the household level and across the housing financing system. These reforms sought to mitigate and manage a variety of risks that are yielding benefits today. One could argue that they have advanced the specific resilience of the housing economy. Beyond risk transfer mechanisms in the capital markets and the elimination of highly risky loans, banks and mortgage servicers are much more reluctant to foreclosure recognizing that the weight of the empirical evidence suggests that alternative work-outs are far more effective in maintaining the asset value of mortgages and housing collateral. Whether it is loan forbearance or debt reduction, these lessons have since helped local housing markets stabilize following countless hurricanes and forest fires in the past decade (Gallagher and Hartley 2017). In the coming years, we will likely also have a much better sense of what works and what does not work in light of current congressionally allocated emergency subsidies and their effect in stabilizing local economies and housing markets. In particular, we are currently undergoing the most widespread set of experiments in rental housing stabilization every undertaken and the lessons from this will likely shape future resilience and post-disaster recovery efforts that engage housing stabilization for generations to come.

So, the question remains: what are we learning about our use and design of the built environment today in the midst of the COVID crisis that might shape future resilience efforts? The intimacy of social isolation has afforded us the luxury of seeing and experiencing our built environment in a very different way. From the lower occupancy rates of grocery stores to the social spaces partitioned within even a single room, there is much to be explored. Most immediately, building managers are actively developing infectious disease control protocols for operating and cleaning buildings. They are thinking about weak links in HVAC systems, filtration standards, and the prospects for transmission in common areas (NMHC 2020). These emerging practices are also likely to advance greater attentiveness to indoor air quality as people spend significantly more time inside than usual. Other adaptations are perhaps less applicable, such as new signage requiring single occupancy elevator rides. Yet, other mundane challenges associated with providing access to quarters for coin operated laundry serving tens of millions of American renters may be a key preparation in the future. While resilience techniques for multi-family buildings are comparatively mature, additional operational and performance standards are likely to originate from COVID (Schoeman 2015).

The design of residential housing is a reflection of our cultural construction of home and its domestic attributes. The domestic realities—good and bad—are compressed in time and spaces over the course of disasters. What happens when long periods of isolation leads to domestic violence? Perhaps a resilience standard might require the installation of locks on interior doors. Ensuring safe spaces might actually require the design of safe spaces. The intimacy of social relationships also plays out for families who are remotely working in spaces designed almost exclusively for entertainment, leisure and domestic pursuits. This requires new forms of multi-purpose furniture and adaptive swing spaces where eating, working and study spaces overlap. While consumer design preferences are unlikely to overcorrect to the COVID experience, there are subtle adaptations that are likely to be positive. People are more sensitive to storage and their overall consumption. They are finding ways to recycle materials and fix things that they might have otherwise simply replaced. This economization of material speaks to social learning that is likely to have a positive impact on the resilience of the built environment when the next disaster strikes. Just in terms of disaster preparedness, many families will now not only have stockpiles of food and medicine, they will also have things like home medical diagnostic equipment (e.g., iPhone compatible portables EKG devices) and home school education materials. All of these preparations are critically important, especially at a time when COVID is significantly weakening our national emergency response capacities for hurricanes, floods, forest fires and other labor intensive disasters.

Beyond the household, the novel experiences with the built environment are extending into streetscapes, parks and other forms of public space. Times of disaster do intensify out biophilic behaviors, but they also highlight the fundamental values associated with investments in public space and the natural environment (Tidball 2012). With many fewer cars on the streets, a new civic realm may be envisioned that supports a more sustainable worldview of the built environment, including what it means to have a reduction in health impacts associated with air pollution (Dutheil et al. 2020). These renewed landscapes are the grounds where people are mobilizing new commitments for physical exercise—once speculated to be a major indicator of community resilience by the U.S. government (FEMA 2016). Like New Year's resolutions, these behaviors are likely to fade in a post-COVID recovery. Yet, they offer valuable insight into where priorities for resilience should be defined and the role that the built environment plays in supporting those priorities.

15.4 COVID and Climate Highlight Limitations of Current Resilience Thinking

The relative maturity of the utilization of resilience designs and policies is a consequence of several limitations inherent in broader epistemological framings of resilience (Davidson et al. 2016). First, the great diversity of different types of resilience has worked against a singular definition or concept of resilience (Moser et al. 2019). This diversity of different types of resilience has not fully appreciated or applied at-scale in resilience policy, although this is quickly changing (Keenan 2018b). Second, among the various types or categories of resilience, the predominant definitions relate to engineering and disaster resilience (Keenan 2017, 2018a). Under these categories, resilience performance is based on internal designs (and corresponding assumptions about the future) that seek to develop a robust capacity for an elasticity to a single-equilibrium state in response to known phenomena (NIST 2015; Kurth et al. 2019). While multiple potential stable states are possible in ecological and community resilience, engineering resilience is not well suited for a certain variance or uncertainty associated with the nature of such future states whose conditions or parameters differ much from the assumptions at the point of design. In this sense, many applications in engineering resilience tend to be largely deterministic (Hosseini et al. 2016). While there are probabilistic attributes to performance, they are functionally measures of reliability (Guidotti et al. 2019; Pettersen and Schulman 2019). As will be discussed, with advances in social learning, machine learning within mechanical systems, and network intelligence, there is an opportunity to conceptualize broader domains of multi-state performance for engineering resilience within the built environment (Rajkovich and Okour 2019). For now, the empirical and descriptive evidence of resilience largely tracks in favor of specific resilience at a finite unit of measurement and not general resilience (Yu et al. 2020), insofar as there has been observed resilience performance across multiple panarchic scales (Linkov and Trump 2019).

The built environment offers a convenient scale of time and space to position resilience in its material and designed manifestations. But, a focus on engineering resilience in the built environment often disregards the ongoing social learning and capability defining processes associated with more normative types of resilience (e.g., socioecological, urban, community) (Thomas et al. 2019). Pandemics and climate change impacts have both spatial and non-spatial attributes that intersect with the built environment. Although human and environmental health may otherwise be inextricably linked, the socialization of disease is distinct in its complexity (Gamhewage 2016; Marmarosh et al. 2020) from the socialization of the communication of risk and uncertainty associated environmental hazards (Krüger et al. 2015). As a cognitive proposition, there is a certain tangibility with climate impacts that comes with the visceral nature of extreme events. Yet, both share an invisibility that serves to both paralyze and mobilize social behavior (Gordy 2016).

As others have point to in this book, a singular focus on vaccines as a means to achieve societal resilience operates to crowd out intervening structural and non-structural opportunities to assess and manage systematic and interdependent risk. By the same token, one could argue that a dominant focus historically on climate mitigation and carbon reduction has—in some contexts—imbued a certain overreliance on a technologically derived solution to planetary resilience, as is represented in geoengineering discourses (Kahan et al. 2015). In this sense, a narrow conceptualization of general resilience across scales is often clouded by a focus on a limited number of pathways for achieving specific resilience (Thorén 2020). Therefore, the initial starting point for a society's conceptualization of a range of resilience "solutions" likely shapes the capacity to learn and adapt as new information and new solutions develop. Resilience research and practice has not yet articulated how hegemonic discourses or dominant strains of communication exchange in a social system can be overcome to circulate an exchange of communication that is drawn upon a great diversity of knowledge that is likely critical for expanding multiple pathways for achieving multiple stable states (Zhang et al. 2020). Therefore, intelligence is a two-way (or multilateral) street. Policy-makers and managers need intelligence about risks and impacts, but they also need to communicate intelligence about opportunities, interventions and strategies that may be diffused in the name of application for achieving specific resilience (Buzzanell and Houston 2018)

To the contrary, the current pandemic highlights the limitation of disaster resilience that has multiple defining singularities between impact and response—or preparation. Few observers could have anticipated that the Russia and the U.S., among other states, are engaged in a deep multilateral information war that clouds both impact assessment and response capability (Landon-Murray et al. 2019; Islam et al. 2020). The mechanisms of disinformation in the U.S. have operated to limit social behavioral that would have otherwise been anticipated to be a key determinant of community resilience to COVID transmission and collateral economic impacts (Ågerfalk et al. 2020; Ma et al. 2020). Again, unidirectional risk communications is not the same thing as managed omnidirectional communication of exposure and resilience pathways. Resilience practices in control systems have not yet entered into more positivist and affirmative actions associated with not only data collection but also data projection and manipulation (e.g., data flow management) (Green et al. 2016). For instance, the question arises as to whether resilience should shift away from the passive aspect of exposure assessment and socialization to more affirmative aspects of (true) information diffusion? This may include censorship of untrue information, as well as some true information that is either not contextual or is otherwise deemed an acceptable threshold of collateral damage. Although federal U.S. resilience policy was largely shifted into national security apparatus during the Obama administration (Keenan 2017), there appears to be limited utilization of "projected forward" strategies for managing communication and socialization (Hamilton 2016).

Resilience—particularly socio-ecological resilience—is also dependent on some measure of social consensus concerning the costs and trade-offs of any given intervention or strategy advanced in the name of resilience (De Kraker 2017). The consensus problem has also been extended to multi-agent networks to undermine accuracy and vector coordination (Abbas et al. 2020). These problems are, in part, centered on resource allocation and the proposition that resilience always has a cost, even if that is an opportunity cost. Resilience research has increasingly matured around various impact and cost methodologies, as well as a delineation of the value-add logic associated with co-benefits (Fung and Helgeson 2017). But, this body of research tends to operate under assumptions around rational wealth maximization and has not further the arbitration of power imbalances, altruistic behavior and non-monetary values that drive entrenched behaviors and locked-in institutions (Olsson et al. 2015).

For instance, with COVID, there is no consensus concerning the values (moral or amoral) that define an acceptable threshold of mortality versus economic mobilization (Chilton et al. 2020). Is this because we are attempting to achieve general resilience across too large of a heterogeneous human geography? Would consensus be achievable within more localized units of analysis that offer great homogeneity in shared values? If homophilous information is key to the diffusion of innovation, then one could surmise the limitations of general resilience as being consistent with the boundaries of such homophily between producers and consumers of innovation. Yet, others have argued that producer-consumer binary does not account for a broader ecosystem of resource integrators that may be central to resilience pathways (Vargo et al. 2020). That challenge is that spatial boundaries for resilience performance may work well for physical and biophysical climate impacts, but may be less effective given the complexity of human mobility. Again, the challenge is to conceptualize modes of communication transmission associated with adaptive learning and reorganization that yield material and spatial results in the built environment, but are themselves constructed on axes of space that are external to conventional management decisions and information within the built environment.

These types of communication and knowledge aggregation necessitate technologies that themselves present opportunities, risks and uncertainties for resilience policy design. The opportunities rest for advanced insight that are beyond the institutional capacity of policymakers and decision makers to fully capture and utilize. The uncertainties center on whether this information can be shaped into intelligence conduits that actually inform or guide effective, efficient, and fair decision making. Automation has its ethical limits and trade-offs are laden with the judgements and biases of the designers of such systems. Because, a multilateral communication system has been argued for, then the flow of information from decision makers leaves the technology, as a tool of resilience, vulnerable to political and counterintelligence manipulation. While safe guards may be systematized, human error and fallibility can never been removed—only mitigated.

Yet, it is arguable undeniable that resilience intelligence must eventually move in this direction. As meta-models incorporate internally designed measurements from engineering resilience performance indicators within built environment infrastructure, there is a decreasing marginal utility of the information without the advanced capacity to manage and interpret the information. In this sense, the technology is constantly defining the value of the information. Again, value assignment has its limitations, but, at this juncture, there is no turning back. This emergence of low-cost measurement hardware interconnected through the internet-of-things (IoT) opens up a broader range of states and spaces from which resilience intelligence may draw utility and surveillance of everything from first and second order exposure to elements that define adaptive capacity for identifying, resourcing and executing resilience and adaptation interventions (Hussein et al. 2018; Keenan 2019).

Between physical measurement and communication intelligence, resilience intelligence may be centrally limited by predetermined conceptualizations of optimal or normative stable regimes. Therefore, it is ultimately the adaptive capacity of coupled decision and measurement technologies to redefine a resilience value system. Without this capacity, any coupled system would be nearly totalizing without any check on legal, economic and technological limits. It would be nothing more than a more complex heuristic of existing stationarity, hence yielding a deterministic order with narrowly defined thresholds and frontiers.

All of this is to raise a broader question: must resilience learn? Can it operate to reorganize capital, rules and processes in order to maintain flexible notations of identify without the need for social learning? On some level, this is already happening with machine learning in the built environment (Keenan 2014). But, ultimately if resilience is to be in service of anthropocentric ends it must serve as an agent for shaping social behavior and norms. COVID and climate change highlight this parallel set of policy ambitions—physical and social—that are centered on the proposition that human and ecological health and welfare converge across multiple domains of resilience theory and practice.

15.5 Conclusions

Learning from disasters is critical. In the heat of the moment, we have the opportunity to observe what is working and what is not working—and for whom. As this chapter highlights, existing COVID responses have likely benefited from recent resilience planning efforts largely advanced in the name of addressing climate change and disaster mitigation. In particular, public health and healthcare management contributions to a broader interdisciplinary field of inquiry associated with community resilience have likely translated into meaningful action that could very well reciprocally advance resilience activities in other sectors. Specific to the healthcare sector, considerations relating to the resilience and adaptive capacity of the built environment are central to managing of the existing challenges associated with supply constraints, alternative forms of service delivery, and the broader continuity of operations. In the linkage between prior disaster experience—some of which are attributable to climate change impacts—and COVID, we find a measure of maturity in the human health and healthcare sectors that provides hope for the progressive development of core practices and strategies associated with disaster, organizational and engineering resilience.

The COVID experience has also imposed new perspectives on the role housing and the built environment in shaping resilience interventions and capacities as viewed through the lens of domiciliaries, consumers, and civic actors. From the management of social space to disaster preparedness, the built form is a conduit for shaping positive behaviors that are the heart of any frame for community resilience. While some ad hoc COVID responses will soon fade, others will sustain as part of our collective adaptive capacity for addressing future social and environmental shocks and stresses.

Finally, COVID and climate change offer many insights into the limitations of the dominant strains of resilience thinking and practice. In particular, resilience struggles to move away from vulnerability assessment and response and engage wider domains beyond stationary exposure analysis. In this context, resilience has yet to fully come to terms with social learning and the management of communication—both in terms of value-add innovation and even misinformation. In this sense, resilience must diversify from reactive stimulus to more proactive adaptive pathways that benefit from resource integrators. This requires a mental shift away from producer and consumer (or beneficiary) dynamics that dominate resilience policy design. By harnessing a combination of machine and human learning, resilience opens the door for a broader diversity of intelligence capacities for identifying and resourcing resilience interventions.

In these times of crisis, it is worth recognizing that the future of research and practice across various domain of resilience and adaptation will be defined not only by the quantifications of socioeconomic indicators but also by the qualification of the human experience in all its capacities for ingenuity, empathy, and moral responsibility. Engineering resilience in complex systems is tasked engaging a broader range of human actors in thinking through not only organizational but also sub-systematic social configurations. Whether it is the advancement of human health or the design of architecture and the built environment, we are reminded that learned resilience is a uniquely human endeavor. The built environment brings a material element to what is increasingly an immaterial and non-spatial advancement of technology from which we struggle to harness its true potential.

Disclaimer: This chapter is based, in part, on prior published research in the special issue on "Risk and resilience in the time of the COVID-19 crisis" (Igor Linkov and Benjamin D. Trump, editors) of Springer's Journal *Environment Systems and Decisions, v40(2), 2020.*

References

Abbas W, Shabbir M, Li J, Koutsoukos X (2020) Interplay between resilience and accuracy in resilient vector consensus in multi-agent networks. arXiv:2009.02417

Ågerfalk PJ, Conboy K, Myers MD (2020) Information systems in the age of pandemics: COVID-19 and beyond. Eur J Inf Syst 29(3):203–207. https://doi.org/10.1080/0960085X.2020.1771968

Aghapour AH, Yazdani M, Jolai F, Mojtahedi M (2019) Capacity planning and reconfiguration for disaster-resilient health infrastructure. J Build Eng 26: https://doi.org/10.1016/j.jobe.2019.100853

AlDossary S, Martin-Khan MG, Bradford NK, Smith AC (2017) A systematic review of the methodologies used to evaluate telemedicine service initiatives in hospital facilities. Int J Med Inform 97:171–194. https://doi.org/10.1016/j.ijmedinf.2016.10.012

Burton CG (2015) A validation of metrics for community resilience to natural hazards and disasters using the recovery from Hurricane Katrina as a case study. Ann Assoc Am Geogr 105 (1):67–86. https://doi.org/10.1080/00045608.2014.960039

Buzzanell PM, Houston JB (2018) Communication and resilience: multilevel applications and insights—a Journal of Applied Communication Research forum. J Appl Commun Res 46(1):1–4. https://doi.org/10.1080/00909882.2017.1412086

Caminade C, McIntyre KM, Jones AE (2019) Impact of recent and future climate change on vector-borne diseases. Ann N Y Acad Sci 1436(1):157–173. https://doi.org/10.1111/nyas.13950

City of Miami (2020) Miami forever climate ready plan. Office of the Chief Resilience Officer, City of Miami, Miami, FL. https://www.miamigov.com/Government/MiamiForeverClimateReady

Chilton S, Nielsen JS, Wildman J (2020) Beyond COVID-19: how the 'dismal science' can prepare us for the future. Health Econ. https://doi.org/10.1002/hec.4114

Cutter SL, Derakhshan S (2019) Implementing disaster policy: exploring scale and measurement schemes for disaster resilience. J Homel Secur Emerg Manag 16(3). https://doi.org/10.1515/jhsem-2018-0029

Davidson J, Jacobson C, Lyth A, Dedekorkut-Howes A, Baldwin C, Ellison J, Holbrook N, Howes M, Serrao-Neumann S, Singh-Peterson L, Smith T (2016) Interrogating resilience: toward a typology to improve its operationalization. Ecol Soc 21(2):Art 27

De Kraker J (2017) Social learning for resilience in social–ecological systems. Curr Opin Environ Sustain 28:100–107

Desai SP, Harris CA, Gordon J (2019) The economic impact of hurricane evacuations on a coastal Georgia hospital: a case study. Front Public Health 7:149. https://doi.org/10.3389/fpubh.2019.00149

Djalante R, Shaw R, DeWit A (2020) Building resilience against biological hazards and pandemics: COVID-19 and its implications for the Sendai Framework. Prog Disaster Sci 100080. https://doi.org/10.1016/j.pdisas.2020.100080

Dutheil F, Baker JS, Navel V (2020) COVID-19 as a factor influencing air pollution? Environ Pollut. https://doi.org/10.1016/j.envpol.2020.114466

Elrod JK, Fortenberry JL (2017) The hub-and-spoke organization design: an avenue for serving patients well. BMC Health Serv Res 17(1):25–33. https://doi.org/10.1186/s12913-017-2341-x

Federal Emergency Management Agency (FEMA) (2016) Draft interagency concepts of community resilience indicators and national-level measures. U.S. Department of Homeland Security, Washington, D.C. https://www.fema.gov/media-library-data/1466085676217-a14e229a461adfa574a5d03041a6297c/FEMA-CRI-Draft-Concept-Paper-508_Jun_2016.pdf

Flynn S (2018) Higher ground: the sophisticated healthcare response of the Southeast Texas Regional Advisory Council to Hurricane Harvey. The Global Resilience Institute, Northeastern University/South East Texas Regional Advisory Council, Boston, MA. https://globalresilience.northeastern.edu/app/uploads/2020/01/The-Sophisticated-Healthcare-Response-of-the-SouthEast-Texas-Regional-Advisory-Council-to-Hurricane-Harvey.pdf

Fung JF, Helgeson JF (2017) Defining the resilience dividend: accounting for co-benefits of resilience planning (No. Technical Note (NIST TN)-1959). National Institute of Standards and Technology (NIST), Gaithersburg, MD

Gallagher J, Hartley D (2017) Household finance after a natural disaster: the case of Hurricane Katrina. Am Econ J: Econ Policy 9(3):199–228. https://doi.org/10.1257/pol.20140273

Gillard R (2016) Questioning the diffusion of resilience discourses in pursuit of transformational change. Glob Environ Polit 16(1):13–20

Gordy M (2016) The invisibility of disaster risks. In: Disaster risk reduction and the global system. Springer, Cham, CH, pp 43–46

Gamhewage GM (2016) Viewpoints on current issues: socializing outbreak response—community engagement and other risk communication interventions. J Commun Healthc 9(1):7–10

Green B, Krotofil M, Hutchison D (2016) Achieving ICS resilience and security through granular data flow management. In: Proceedings of the 2nd ACM workshop on cyber-physical systems security and privacy, pp 93–101, Oct 2016. https://doi.org/10.1145/2994487.2994498

Guidotti R, Gardoni P, Rosenheim N (2019) Integration of physical infrastructure and social systems in communities' reliability and resilience analysis. Reliab Eng Syst Saf 185:476–492

Hamilton DS (2016) Going beyond static understandings: resilience must be shared, and it must be projected forward. In: Critical infrastructure projection against hybrid warfare security related challenges. IOS Press, Washington, D.C.

Henly-Shepard S, Gray SA, Cox LJ (2015) The use of participatory modeling to promote social learning and facilitate community disaster planning. Environ Sci Policy 45:109–122. https://doi.org/10.1016/j.envsci.2014.10.004

Hosseini S, Barker K, Ramirez-Marquez JE (2016) A review of definitions and measures of system resilience. Reliab Eng Syst Saf 145:47–61

Humphries BE (2019) Critical infrastructure: emerging trends and policy considerations for congress. R45809. Congressional Research Service, Washington, D.C.

Hussein A, Chehab A, Kayssi A, Elhajj IH (2018) Machine learning for network resilience: the start of a journey. In: 2018 fifth international conference on software defined systems (SDS). IEEE, pp 59–66, Apr 2018. https://doi.org/10.1109/sds.2018.8370423

Islam MS, Sarkar T, Khan SH, Mostofa Kamal AH, Hasan SM, Kabir A, Yeasmin D, Islam MA, Chowdhury KIA, Anwar KS, Seale H, Chughtai AA (2020) COVID-19—related infodemic and its impact on public health: a global social media analysis. Am J Trop Med Hyg tpmd200812. https://doi.org/10.4269/ajtmh.20-0812

Kahan DM, Jenkins-Smith H, Tarantola T, Silva CL, Braman D (2015) Geoengineering and climate change polarization: testing a two-channel model of science communication. Ann Am Acad Polit Soc Sci 658(1):192–222

Keenan JM (2014) Material and social construction: a framework for the adaptation of buildings. Enq: J Archit Res 11(1):18–32. https://doi.org/10.17831/enq:arcc.v11i1.271

Keenan JM (2015) From sustainability to adaptation: a case study of Goldman Sach's corporate real estate strategy. Build Res Inf 43(6):407–422. https://doi.org/10.1080/09613218.2016.1085260

Keenan JM (2017) From climate change to national security: an empirical analysis of the Obama administration's federal resilience mandates and measures. Nat Hazards Rev 19(1):0401722. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000273

Keenan JM (2018a) Types and forms of resilience in local planning in the US: who does what? Environ Sci Policy 88:116–123. https://doi.org/10.1016/j.envsci.2018.06.015

Keenan JM (2018b) Climate adaptation finance and investment in California. Routledge, London, UK

Keenan JM (2019) A climate intelligence arms race in financial markets. Science 365(6459):1240–1243. https://doi.org/10.1126/science.aay8442

Kleinman A, Watson JL (2006) SARS in China: prelude to pandemic?. Stanford University Press, Palo Alto, CA

Krüger F, Bankoff G, Cannon T, Orlowski B, Schipper ELF (eds) (2015) Cultures and disasters: understanding cultural framings in disaster risk reduction. Routledge, New York, NY

Kurth MH, Keenan JM, Sasani M, Linkov I (2019) Defining resilience for the US building industry. Build Res Inf 47(4):480–492

Landon-Murray M, Mujkic E, Nussbaum B (2019) Disinformation in contemporary US foreign policy: impacts and ethics in an era of fake news, social media, and artificial intelligence. Public Integr 21(5):512–522

Lichtveld M (2018) Disasters through the lens of disparities: elevate community resilience as an essential public health service. Am J Public Health. https://doi.org/10.2105/AJPH.2017.304193

Linkov I, Trump BD (2019) Panarchy: thinking in systems and networks. In: The science and practice of resilience. Springer, Cham, CH, pp 35–44

Ma X, Vervoort D, Luc JG (2020) When misinformation goes viral: access to evidence-based information in the COVID-19 pandemic. J Glob Health Sci 2(1): https://doi.org/10.35500/jghs.2020.2.e13

Mandal S (2017) The influence of organizational culture on healthcare supply chain resilience: moderating role of technology orientation. J Bus Ind Mark 32(8):1021–1037. https://doi.org/10.1108/JBIM-08-2016-0187

Marmarosh CL, Forsyth DR, Strauss B, Burlingame GM (2020) The psychology of the COVID-19 pandemic: a group-level perspective. Group Dyn: Theory Res Pract 24(3):122–138. https://doi.org/10.1037/gdn0000142

Moser S, Meerow S, Arnott J, Jack-Scott E (2019) The turbulent world of resilience: interpretations and themes for transdisciplinary dialog. Clim Change. https://doi.org/10.1007/s10584-018-2358-0

National Institutes of Standards and Technology (2015) Community resilience planning guide for buildings and infrastructure systems, vol 1. U.S. Department of Commerce, Washington, D.C. https://doi.org/10.6028/nist.sp.1190v1

National Multifamily Housing Council (2020) Coronavirus preparedness for apartment firms. National Multifamily Housing Council, Washington, D.C. https://www.nmhc.org/research-insight/analysis-and-guidance/emergency-preparedness/coronavirus-preparedness-for-apartment-firms/

Olsson L, Jerneck A, Thoren H, Persson J, O'Byrne D (2015) Why resilience is unappealing to social science: theoretical and empirical investigations of the scientific use of resilience. Sci Adv 1(4): https://doi.org/10.1126/sciadv.1400217

Pettersen KA, Schulman PR (2019) Drift, adaptation, resilience and reliability: toward an empirical clarification. Saf Sci 117:460–468

Powell T, Hanfling D, Gostin LO (2012) Emergency preparedness and public health: the lessons of Hurricane Sandy. J Am Med Assoc 308(24):2569–2570. https://doi.org/10.1001/jama.2012.108940

Rajkovich NB, Okour Y (2019) Climate change resilience strategies for the building sector: examining existing domains of resilience utilized by design professionals. Sustainability 11 (10):2888

Schoeman L (2015) Ready to respond: strategies for multifamily building resilience. Enterprise Community Partners, Washington, D.C. https://www.enterprisecommunity.org/resources/ready-respond-strategies-multifamily-building-resilience-13356

Semenza JC, Menne B (2009) Climate change and infectious diseases in Europe. Lancet Infect Dis 9(6):365–375

Seltenrich N (2018) Safe from the storm: creating climate-resilient health care facilities. Environ Health Perspect 126(10). https://doi.org/10.1289/ehp3810

Shimpo N, Wesener A, McWilliam W (2019) How community gardens may contribute to community resilience following an earthquake. Urban For Urban Green 38:124–132. https://doi.org/10.1016/j.ufug.2018.12.002

Sunstein CR (2006) The availability heuristic, intuitive cost-benefit analysis, and climate change. Clim Change 77(1–2):195–210. https://doi.org/10.1007/s10584-006-9073-y

Tidball K (2012) Urgent Biophilia: human-nature interactions and biological attractions in disaster resilience. Ecol Soc 17(2). https://doi.org/10.5751/es-04596-170205

Thomas JE, Eisenberg DA, Seager TP, Fisher E (2019) A resilience engineering approach to integrating human and socio-technical system capacities and processes for national infrastructure resilience. J Homel Secur Emerg Manag 16(2). https://doi.org/10.1515/jhsem-2017-0019

Thorén H (2020) Against general resilience. In: Routledge handbook of urban resilience. Routledge, London, U.K., pp 26–34

U.S. Climate Resilience Toolkit (USCRT) (2016) Building health care sector resilience. National Oceanographic and Atmospheric Administration, Washington, D.C. https://toolkit.climate.gov/topics/human-health/building-climate-resilience-health-sector

Vargo SL, Akaka MA, Wieland H (2020) Rethinking the process of diffusion in innovation: a service-ecosystems and institutional perspective. J Bus Res 116:526–534. https://doi.org/10.1016/j.jbusres.2020.01.038
Verheul ML, Dückers ML (2020) Defining and operationalizing disaster preparedness in hospitals: a systematic literature review. Prehospital Disaster Med 35(1):61–68. https://doi.org/10.1017/S1049023X19005181
World Health Organization (WHO) (2018) WHO health evidence network synthesis report: what quantitative and qualitative methods have been developed to measure health-related community resilience at a national and local level. World Health Organization, Copenhagen, DK. https://apps.who.int/iris/handle/10665/326228
Yang Y, Peng F, Wang R, Guan K, Jiang T, Xu G, Chang C (2020) The deadly coronaviruses: the 2003 SARS pandemic and the 2020 novel coronavirus epidemic in China. J Autoimmun 109 (1): https://doi.org/10.1016/j.jaut.2020.102434
Young OR (2010) Institutional dynamics: resilience, vulnerability and adaptation in environmental and resource regimes. Glob Environ Change 20(3):378–385. https://doi.org/10.1016/j.gloenvcha.2009.10.001
Yu DJ, Schoon ML, Hawes JK, Lee S, Park J, Rao PSC, Ukkusuri SV (2020) Toward general principles for resilience engineering. Risk Anal. https://doi.org/10.1111/risa.13494
Zhang Q, Hu J, Song X, Li Z, Yang K, Sha Y (2020) How does social learning facilitate urban disaster resilience? A systematic review. Environ Hazards 19(1):107–129
Zhong S, Clark M, Hou XY, Zang Y, FitzGerald G (2014) Validation of a framework for measuring hospital disaster resilience using factor analysis. Int J Environ Res Public Health 11 (6):6335–6353. https://doi.org/10.3390/ijerph110606335

Chapter 16
The COVID-19 Pandemic: Lessons for Urban Resilience

Ayyoob Sharifi

Abstract Following its emergence in China in December 2019, COVID-19 rapidly spread across many cities around the globe, causing significant socio-economic impacts. Long before the pandemic, enhancing urban resilience was high on the agenda of urban planners and policy makers alike. However, the focus has mainly been on resilience to seismic hazards and climate change impacts. The pandemic has brought to the fore issues related to the vulnerability of cities to infectious diseases and provides an unprecedented opportunity for critical reflections and debates about major issues that need to be addressed and lessons that can be learned to better deal with future similar events. As a preliminary effort, this chapter discusses lessons related to various areas such as economy, environmental management, governance, social inequality, smart cities, transportation, and urban design. In the light of early evidence reported on these areas in the literature, this study will discuss possible links between the pandemic and the planning, absorption, recovery, and adaptation capacities of resilience. It will also discuss the significance of major characteristics such as flexibility, collaboration, diversity, redundancy, resourcefulness, and self-organization for enhancing those resilience capacities. In addition, among other things. this chapter emphasizes the importance of pre-event planning, long-term visioning, early response, integrated governance, community empowerment, and appropriate use of smart city solutions for resilience against pandemics.

Keywords COVID-19 · Urban resilience · Planning · Absorption · Recovery · Adaptation

A. Sharifi (✉)
Graduate School of Humanities and Social Sciences, Hiroshima University, Hiroshima, Japan
e-mail: sharifi@hiroshima-u.ac.jp

Graduate School of Advances Science and Engineering, Hiroshima University, Hiroshima, Japan

Network for Education and Research on Peace and Sustainability, Hiroshima University, Hiroshima, Japan

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_16

16.1 Introduction

In early 2020, COVID-19 ravaged through many countries around the world, causing significant economic and human losses. According to the COVID-19 Dashboard by the Center for Systems Science and Engineering at Johns Hopkins University, as of November 20, 2020 the total number of confirmed cases and deaths was 56,804,454 and 1,358,489, respectively. It is likely that the pandemic will continue to spread until vaccines are developed and disseminated widely. The high concentration of population and economic activities in cities makes them potentially vulnerable to any disruptive events and this recent pandemic is no exception. In fact, in many countries, cities have been epicenters and hotspots of the pandemic.

While the significance of enhancing urban resilience was well recognized long before the pandemic, knowledge on resilience to disease outbreaks and pandemics was very limited, and the focus was mainly on seismic risks and climate change impacts (Sharifi 2020). The pandemic has once again exposed the potential vulnerabilities of urban areas and has placed resilience-building activities high on the agenda of planners and policy makers.

Resilience is a polysemic term that has been defined differently in different disciplines and there is still no single, universally accepted definition for it. However, three major approaches to defining urban resilience can be distinguished from the urban studies literature, namely, engineering resilience, ecological resilience, and adaptive resilience. Engineering resilience emphasizes minimizing the risk of failure through increasing robustness. In case of disruptions, it aims to facilitate rapid return to pre-disruption equilibrium conditions. In the ecological approach, the probability of failure is better recognized. This approach emphasizes having a certain level of tenacity to endure shocks without losing the fundamental characteristics and functionalities of the system. As a result, the post-shock equilibrium status of the system may be different from its original one. Finally, the adaptive approach that is adopted for discussions in this chapter entails the basic features of the former approaches, but it has more emphasis on learning from shocks and does not require returning to equilibrium state(s) (Sharifi and Yamagata 2016). A simple way to make the adaptive conceptualization of resilience more tangible is to define it based on its underlying capacities. In this regard, adaptive resilience is the capacity to “plan and prepare for, absorb, recover from, and more successfully adapt to disruptive events” (TNA 2012). Here, adaptation means not only bouncing back from the shock(s) but also learning lessons from the undesirable experience and apply them to perform better against future shock that may be even more severe. To further clarify what is meant by these capacities, several characteristics such as flexibility, collaboration, diversity, redundancy, resourcefulness, and self-organization have been mentioned in the literature (Sharifi and Yamagata 2016). For instance, collaborative networks and resourcefulness are crucial characteristics for improving the planning capacity.

By making reference to these capacities and characteristics, in the next section urban resilience strengths and weaknesses revealed by the COVID-19 pandemic and potential implications for post-COVID resilience planning will be discussed. This will be done by drawing insights from the early literature published on various areas such as economy, environmental management, governance, social inequality, smart cities, transportation, and urban design.

16.2 Insights from the Literature

The pandemic has affected many aspects of urban life and has already altered lifestyles (Keenan 2020; Sharifi and Khavarian-Garmsir 2020). While long-term impacts are still uncertain, evidence provided on some short- and medium-term impacts makes it possible to discuss implications for urban resilience. These are discussed in the following sections.

16.2.1 Economy

Large scale lockdowns and travel restrictions have negatively affected many cities around the world. These economic difficulties have exposed some major issues with direct and indirect linkages to resilience characteristics and capacities. The most notable issue is related to the significance of diversity in urban economic structure, livelihood options of individuals, and operation modes of small- and medium- sized businesses. Based on early evidence, lack of diversity is likely to increase the scale of economic decline, thereby reducing the absorption and recovery capacities. For instance, cities that are highly dependent on specific industries such as tourism and hospitality have lost a major income source (Krzysztofik et al. 2020). Similarly, individuals with limited skills and livelihood options (e.g., dependent on the tourism industry) have suffered significantly from the crisis (Kunzmann 2020). Having a diverse set of skills would enhance the flexibility to secure other jobs whenever needed. The importance of diversity, in terms of the operation mode, should also be emphasized. The pandemic has further boosted the already growing customers' interest in online shopping. This means that, unless small- and medium-sized enterprises such as inner-city businesses adopt diverse and hybrid businesses structure, their survival would be at risk (Kunzmann 2020).

Diverse economic structure is also likely to contribute to 'self-organization' that is another key resilience characteristic. For instance, disruptions in global supply chain are likely to have significant impacts on cities that do not feature a diverse economic structure and, therefore, rely heavily on imports for meeting their basic needs (Batty 2020). This may, for instance, disrupt food supply chain in cities (Pulighe and Lupia 2020). Accordingly, actions such as investment in urban agriculture for local food production can diversify the supply chain portfolio, thereby improving modularity and self-organization characteristics of cities. Such planning efforts, in turn, strengthen the absorption capacity of cities and enable them to better deal with and adapt to future similar events.

The pandemic has also demonstrated that low-income citizens are hit harder (Creţan and Light 2020). This has major consequences for the absorption and recovery capacities of cities as it would be difficult to persuade low-income households, concerned about meeting basic daily needs, to adhere with response measures such as social distancing and 'stay at home' orders. Consequently, it will probably take more time to flatten the curve and return to normal functionality. Therefore, more attention to reducing inequalities is needed for better resilience to pandemics and other similar shocks.

16.2.2 Environmental Management

The lockdowns and travel restrictions designed to contain the spread of the virus brought transportation and industrial activities to a halt in many countries. One of the first observed impacts of these policies and restrictions were air quality improvements in many cities across the world. In particular, pollutants such as NO_2 and CO that are directly linked to the transportation sector were reduced (Baldasano 2020; Dantas et al. 2020). This provides important adaptation lessons for cities to mitigate urban air pollution in the post-COVID era by greening the transportation sector. A major point, however, that needs to be considered is that in some cities reductions in NO_2 and PM concentration levels have increased the level of secondary pollutants such as O_3 that are detrimental to human health (Sicard et al. 2020). Therefore, integrated approaches that coordinate efforts across different sectors and consider cumulative impacts of different decisions are essential for better adaptation.

Results related to air quality also show that high levels of air pollution are associated with higher rates of infection and mortality (Coccia 2020; Xu et al. 2020; Yao et al. 2020). Furthermore, exposure to pollutants over longer periods of time may weaken the respiratory system of individuals, thereby, making them more vulnerable to infectious diseases (Berman and Ebisu 2020). Therefore, reducing air pollution also contributes to resilience by improving absorption and recovery capacities of individuals.

Lockdowns and travel restrictions have also led to dramatic increases in the quality of surface and groundwater resources in many cities such as Venice (Italy), and Tuticorin (India) (Braga et al. 2020; Hallema et al. 2020). This is attributed to the decline in both point contaminant sources such as industrial units, and non-point sources like vehicular traffic (Hallema et al. 2020). This indicates that adaptive actions such as development and implementation of policies and laws for regulating the sources of contamination can lead to major water quality improvements. Considering that COVID-19 and other pathogens can also spread through fecal-oral routes, such actions can also reduce the likelihood of future outbreaks (Naddeo and Liu 2020). In fact, in addition to risk mitigation, preventing sewage leakage into water resources and appropriate disinfection of water and wastewater plants can also improve absorption and recovery capacities. This is because, for instance, in high-density slums with limited access to sanitation and sewage treatment facilities, lack of access to clean water can diminish the expected positive impacts of stay home and travel restriction measures (Bhowmick et al. 2020).

Presence of the virus in the wastewater also provides an opportunity to detect pandemic hotspots through real-time monitoring and testing of the sewage system using methods enabled by Information and Communication (ICT) systems. Using such early-warning systems, planners and municipality authorities can obtain timely information about the diffusion patterns of the infection and take necessary response measures. Some preliminary efforts to develop of implement such systems have already been made (e.g., see https://www.biobot.io/).

16.2.3 Governance

Adequate planning measures before the occurrence of any disruptive events are critical for mitigating potential losses. Accordingly, resilient urban governance regimes should involve long-term visioning and scenario making to avoid being surprised by shocks. Early evidence reported in the literature confirms that cities that feature long-term planning cultures and have taken pre-event mitigatory measures have been more successful in responding to the COVID-19 crisis (Duggal 2020). In contrast, lack of such mechanisms and policies have resulted in major difficulties and damages in some contexts such as Bangladesh (Shammi et al. 2020). Long-term visioning ensures sufficient preparation for different types of disasters. This not only mitigates risks, but also reduces the overall losses (absorption capacity) and facilitates more rapid recovery through provision of adequate response and recovery equipment and resources. Furthermore, long-term visioning and regular revision of plans improve adaptive capacity through providing opportunities for learning from experiences.

In addition to long-term visioning, smooth coordination of actions across multiple levels of government is also essential for effective absorption and recovery during major disruptive events such as pandemics. For instance, the experience of Australia shows that conflicting objectives of different levels of government have caused confusion and resulted in slow and ineffective response (Steele 2020). In contrast, in countries such as China and Vietnam state-based initiatives have facilitated effective and timely response. However, this should not be interpreted as the desirability of pure top-down policies. In fact, in both China and Vietnam citizen participation and well-coordinated grassroot initiatives have played significant roles in containing the spread of the virus through active engagement in efforts such as raising citizen awareness, communicating risks, sanitizing open and public places, and helping out poor and marginalized groups (Earl and Vietnam 2020; Thoi 2020). Regarding the latter, evidence from India shows that strong Non-Governmental Organizations (NGOs) can also play critical roles as they can ensure providing social and economic support in case the state-based activities fail (Duggal 2020). It should be noted that, in addition to absorption and recovery capacities, citizen engagement can also provide adaptation benefits. In fact, lessons learned via engagement in community-based activities are expected to help citizens better respond to future disruptive events. Overall, a smart combination of top-down and bottom-up governance approaches seems to be more desirable for responding to crises such as the COVID-19 pandemic.

16.2.4 Smart Cities

Smart city solutions enabled by Information and Communication Technologies (ICTs) and big data analytics have transformed many aspects of the everyday life. Although a large body of research exists on various aspects of smart cities, contributions of smart city solutions to urban resilience are rather understudied. The pandemic, therefore, offered an unprecedented opportunity to explore actual and/or potential contributions of smart city solutions to resilience. In response to the pandemic, many cities have adopted smart solutions for different purposes such as identifying infected individuals, detecting virus hotspots, facilitating social distancing, and checking compliance with 'stay home' and quarantine measures. These have contributed to resilience by enabling maintenance of certain levels of functionality. For instance, the reasonable internet coverage in many communities has offered many sectors the flexibility to shift to new equilibrium states. For instance, teleworking has allowed many businesses to continue their operations; online shopping has facilitated continued household access to basic necessities; and remote education has allowed continuity in education (Kunzmann 2020).

Obviously, such benefits have been achieved in places where adequate investments in smart city infrastructure systems have been made before the pandemic. This, again, indicates the significance of long-term visioning. For instance, in Newcastle, UK, the surveillance capacities of the Urban Observatory platform, which collects real-time data on many types of urban activities has allowed timely update of urban management activities in response to the changing needs and demands. In addition, it has facilitated rapid exchange of data between sectors in charge of urban management and emergency response (James et al. 2020). Other utilities have also been reported in other contexts. For instance, drones have been used in China to maintain service delivery while reducing human-to-human contact (Chen et al. 2020). Also, Artificial Intelligence (AI) has been utilized to minimize direct contact between patients and health workers (Chen et al. 2020). These have contributed to resilience by limiting the spread of the outbreak (absorption) and facilitating rapid recovery. Additionally, the predictive abilities of smart solutions and big data analytics can enable better planning and mitigation. Noteworthy examples of this capacity are the travel pattern change prediction abilities of the Newcastle Urban Observatory discussed above and the 'early warning' functions of the smart wastewater surveillance system that was discussed in Sect. 2.2.

Overall, significant potentials of smart city solutions for enhancing resilience against adverse events have been highlighted by the pandemic. This is expected to lead to further investment in smart city projects. However, to maximize the benefits of smart solutions it is essential to ensure equitable access to internet and digital technologies. This is related to the broader issue of social equality that will be discussed in the next section.

16.2.5 Social Issues

Soon after the spread of COVID-19, its differential impacts on minorities, urban poor, and other vulnerable groups were exposed. In fact, COVID-19 once again revealed the deep-rooted inequalities that exist in many developing, as well as, developed country cities (Wade 2020). For instance, according to evidence from New York City, death rate of Black and Latino people is significantly higher than their White counterparts (Wade 2020). Also, the pandemic has hit communities living in informal developments and slum areas of the Global South cities harder (Biswas 2020). The poor, marginalized, and vulnerable groups are often disproportionately affected due to several factors such as lack of access to healthcare not only during the pandemic, but also during their lifetime. In addition, they are more likely to be exposed to environmental pollution and other stressors that may result in the development of pre-existing conditions that, in turn, may increase vulnerability to pandemics such as COVID-19 (Biswas 2020; Wasdani and Prasad 2020).

Such social inequalities may erode the capacity to contain the spread of the virus (i.e., absorption capacity), and make the recovery period longer. This is due to several factors such as livelihood insecurity, limited access to clean water, very high density, and livelihood dependence on close social interactions in poor settlements and slums that make adherence to ‘stay home’ and social distancing orders challenging (de Oliveira and de Aguiar Arantes 2020; Finn and Kobayashi 2020, Kihato and Landau 2020). Therefore, as failure to contain the spread of the virus in some settlements may put the broader society at risk, slum upgrading and reducing social inequalities should be prioritized.

Other social factors that are crucial for resilience against adverse events are sense of community and social capital. There are arguments that the weakened sense of community in some Indian cities is to be blamed for limited capacities to absorb and recover from the pandemic (Biswas 2020). Contrary to this, evidence from Ho Chi Min City, Vietnam signifies the positive impacts of strong sense of community (Thoi 2020). Obviously, strong sense of community and high levels of social capital increase the likelihood of receiving mutual support during difficult times. Additionally, it can strengthen community-driven initiatives that can complement state-oriented efforts. Furthermore, strong sense of community may result in better compliance with social distancing and other rules necessary for effective response and rapid recovery. Some promising examples of how sense of community and engagement in societal support programs have helped communities overcome societal challenges during the COVID-pandemic have been reported in the literature (Cattivelli and Rusciano 2020; Mendes 2020). These include efforts to ensure meeting local food demand in Naples, Italy (Cattivelli and Rusciano 2020), and an initiative aimed at reducing housing insecurity in Lisbon, Portugal (Mendes 2020).

16.2.6 Transportation

High connectivity is likely to intensify the spread rate of COVID-19. Therefore, as expected, significant declines in inter- and intra-city transportation volumes were experienced during the first months after the emergence of the virus. This was driven by traffic restrictions enforced by local governments, as well as, citizens' increasing concerns about being exposed to the virus in crowded areas. Accordingly, evidence from different countries such as Hungary, India, and Netherland shows that transportation demand has reduced significantly following the enforcement of lockdowns (Bucsky 2020; de Haas et al. 2020; Saha et al. 2020). These declines in transportation volumes have been to some extent effective in reducing the transmission rate in cities (Kraemer et al. 2020; Tian et al. 2020).

Despite these trends, not all transportation modes have been affected similarly. Public transportation systems have been hit harder as expected. In contrast, some modes such as cycling have gained increased ridership (Sharifi and Khavarian-Garmsir 2020; Teixeira and Lopes 2020). This may be an indication that active transportation modes are more resilient to pandemics and facilitate shock absorption. Higher flexibility and adaptive capacity of active modes of transportation and their contribution to resilience against other types of adverse events have also been discussed in the literature (Sharifi 2019a, b, c). For instance, active modes are less likely to result in traffic jam during emergency evacuation (Sharifi 2019a, b, c). In addition, active transportation may enhance adaptive capacity through providing long-term health co-benefits, and thereby reducing pre-existing health conditions such as respiratory diseases that increase vulnerability to infectious diseases such as COVID-19. Furthermore, shift to active modes during the pandemics may promote modal shift and long-term transformation in travel behavior. This can be considered as adaptive process that also facilitates other benefits such as climate change mitigation.

One issue that needs careful attention of planners and policy makers is the possible increase in negative attitudes toward public transportation that may lead to significant increase in the ownership and use of private vehicles. As public transportation is generally more robust and resilient against other threats such as flooding, it is essential to take appropriate measures to regain trust in public transportation by addressing health concerns of citizens. This could be achieved through, for example allocating more space to public transportation, promoting remote working, and/or adjusting regular working hours to avoid overcrowding in the public transportation network. Otherwise, rapid increase in private car dependence may cause additional problems in the future and, of course, also make it challenging to meet climate change mitigation objectives.

16.2.7 Urban Design

Physical design of cities can have major implications for the spread of infectious diseases. Generally, cities are identified with higher levels of density and more crowded places that may increase close human interactions. Accordingly, soon after the emergence of COVID-19 in China there were renewed concerns about the desirability of living in high-density cities. However, early evidence indicates that such concerns are not substantiated. Several studies have found no significant relationships between density and the infection and death rates, and some have even reported lower rates in high density areas (Boterman 2020; Qiu et al. 2020). While debates on the association between COVID-19 and density are expected to continue in the coming months, better access to resources in high density areas is probably a major factor that may enhance the absorption and recovery capacities. In addition, residents in dense urban areas are likely to be more cautious and pay more attention to social distancing and other protective measures.

Other noteworthy urban elements that are likely to affect dynamics of the COVID-19 transmission are streets, and open and green spaces. Unless designed appropriately, high density may limit access to sufficient levels of green and open spaces that are necessary for containing the spread of viruses through enforcing social distancing measures and at the same time meeting the recreation demands of citizens. Additionally, many modern cities are car oriented. Therefore, the space allocated to sidewalks is very limited, resulting in congestion. Provision of adequate open and green spaces and redesigning streetscape is, therefore, critical to enhance resilience to future pandemics. Such design measures also provide other resilience co-benefits. For instance, adequate access to open spaces improves evacuation and emergency response programs and well-integrated green space mitigates flooding risk (Sharifi 2019a, b, c).

Therefore, it is safe to say that appropriately designed compact urban development can be in fact resilient to pandemics. It should also not be forgotten that the alternative would be urban sprawl that is argued to undermine resilience against other threats such as flooding and wildfires (Sharifi 2019a, b, c). For instance, emergency response could be delayed due to long driving distances, or flooding and wildfire risks may increase due to unregulated expansion into low-lying and ecologically sensitive areas (Sharifi 2019a, b, c).

Finally, to avoid being caught up in the environmental and physical design determinism fallacy, it should be kept in mind that physical design alone cannot determine resilience or vulnerability of cities. Other social and economic forces that govern our relationships and behaviors within the context of physical design are also essential and should be considered.

16.3 Summary and Conclusions

Since its emergence in late 2019, the COVID-19 pandemic has taken many lives and livelihoods. The pandemic and its impacts offer the opportunity to reflect on our cities and their capacities to deal with shocks and stressors. Drawing on the early evidence reported in the literature, in this chapter I explored various issues related to different themes such as economy, environmental management, governance, smart cities, social inequalities and sense of community, transportation, and urban design that have implications for urban resilience. As shown in Table 16.1, key factors related to these themes have important implications for planning, absorption, recovery, and adaption capacities. Implications are particularly significant for absorption and recovery capacities, indicating the significance of appropriate planning and design measures for containing the virus and facilitating rapid recovery to normal conditions. While planning and adaptation capacities are less highlighted, they are also crucial and need to be prioritized. Enhancing planning capacities contribute to minimizing potential losses, and adaptation capacities are also critical for learning lessons from disasters to ensure better response in the future.

In the light of insights discussed in the previous sections, the following major lessons for urban resilience can be highlighted.

Table 16.1 Key resilience-related factors and their links to underlying resilience capacities

Key resilience-related factors	Capacities that are likely to be influenced			
	Planning	Absorption	Recovery	Adaptation
Diversified economic structure		+	+	
Supply chain diversification		+		+
Economic inequalities		+	+	
Long-term visioning	+	+	+	+
Integrated management featuring a combination of top-down and bottom-up approaches		+	+	+
Smart city solutions	+	+	+	
Sense of community		+	+	+
Social inequalities	+	+	+	
Presence of active transportation systems		+		+
Revitalizing/reforming public transportation systems	+	+		
Appropriate levels of density	+	+	+	
Proper design of open and green spaces	+	+	+	+

- Diversifying economic structure of cities contributes to absorbing shocks and facilitates rapid recovery
- Supply chain diversification and strengthening local supply chain improve urban resilience by enhancing self-organization and independence characteristics
- During pandemics, socio-economic inequalities put the whole society at risk by causing difficulties for containing the spread of the virus. Therefore, taking actions to minimize such inequalities is of critical importance
- Integrated urban management and appropriate combination of top-down and bottom-up measures allow overcoming potential priority conflicts and facilitate rapid response and recovery
- Smart city solutions and big data analytics improve efficacy and efficiency of efforts aimed at identifying and isolating infected individuals. They also facilitate taking timely adaptive measures in response to the changing demands
- Sense of community can be a major resilience-building factor that improves compliance with social distancing measures and facilitates provision of community-based social support
- Active transportation modes such as cycling, and walking are more resilient to pandemics and should be further promoted
- As the pandemic has raised concerns about the safety of public transportation systems, major reforms are needed regain public trust and avoid further dominance of car-oriented developments that lead to serious socio-economic and environmental externalities
- Despite initial concerns, density is not a major risk factor contributing to the spread of COVID-19. Proper design of high-density areas may even improve absorption and recovery capacities
- Sufficient levels of open and green spaces are needed to ensure compliance with social distancing measures that are essential for absorbing the initial shocks of the pandemics. Also, such spaces can meet the outdoor exercise and recreation needs of citizens, thereby strengthening their coping capacity.

At the end, it should be noted that the impacts of the pandemic are yet to be fully known. It is expected that more evidence related to resilience of cities to the pandemic will be published in the coming years. This will make it possible to gain more evidence-based knowledge on the interactions between COVID-19 and urban resilience and possible co-benefits and trade-offs involved in efforts aimed at enhancing resilience to pandemics.

References

Baldasano JM (2020) COVID-19 lockdown effects on air quality by NO2 in the cities of Barcelona and Madrid (Spain). Sci Total Environ 741

Batty M (2020) The Coronavirus crisis: what will the post-pandemic city look like? Environ Plann B Urb Anal City Sci 47(4):547–552

Berman JD, Ebisu K (2020) Changes in U.S. air pollution during the COVID-19 pandemic. Sci Total Environ 739
Bhowmick GD, Dhar D, Nath D, Ghangrekar MM, Banerjee R, Das S, Chatterjee J (2020) Coronavirus disease 2019 (COVID-19) outbreak: some serious consequences with urban and rural water cycle. npj Clean Water 3(1)
Biswas PP (2020) Skewed urbanisation and the contagion. Econ Political Weekly 55(16):13–15
Boterman WR (2020) Urban-rural polarisation in times of the Corona outbreak? The early demographic and geographic patterns of the SARS-CoV-2 epidemic in the Netherlands. Tijdschrift voor Economische en Sociale Geografie
Braga F, Scarpa GM, Brando VE, Manfè G, Zaggia L (2020) COVID-19 lockdown measures reveal human impact on water transparency in the Venice Lagoon. Sci Total Environ 736
Bucsky P (2020) Modal share changes due to COVID-19: the case of Budapest. Trans Res Interdiscip Perspect 100141
Cattivelli V, Rusciano V (2020) Social innovation and food provisioning during Covid-19: the case of urban-rural initiatives in the Province Of Naples. Sustain (Switzerland) 12(11)
Chen B, Marvin S, While A (2020) Containing COVID-19 in China: AI and the robotic restructuring of future cities. Dialogues Human Geogr
Coccia M (2020) Factors determining the diffusion of COVID-19 and suggested strategy to prevent future accelerated viral infectivity similar to COVID. Sci Total Environ 729:
Creţan R, Light D (2020) COVID-19 in Romania: transnational labour, geopolitics, and the Roma ‘outsiders’. Eurasian Geogr Econ: 1–14
Dantas G, Siciliano B, França BB, da Silva CM, Arbilla G (2020) The impact of COVID-19 partial lockdown on the air quality of the city of Rio de Janeiro, Brazil. Sci Total Environ 729
de Haas M, Faber R, Hamersma M (2020) How COVID-19 and the Dutch ‘intelligent lockdown’ change activities, work and travel behaviour: evidence from longitudinal data in the Netherlands. Transp Res Interdiscip Perspect 6:
de Oliveira LA, de Aguiar Arantes R (2020) Neighborhood effects and urban inequalities: the impact of Covid-19 on the periphery of Salvador, Brazil. City Soc 32(1)
Duggal R (2020) Mumbai’s struggles with public health crises from plague to COVID-19. Econ Polit Weekly 55(21):17–20
Earl C, Vietnam RMIT (2020) Living with authoritarianism: Ho Chi Minh City during COVID-19 Lockdown. City Soc
Finn BM, Kobayashi LC (2020) Structural inequality in the time of COVID-19: urbanization, segregation, and pandemic control in sub-Saharan Africa. Dialogues Human Geogr
Hallema DW, Robinne FN, McNulty SG (2020) Pandemic spotlight on urban water quality. Ecolog Process **9**(1)
James P, Das R, Jalosinska A, Smith L (2020) Smart cities and a data-driven response to COVID-19. Dialogues Human Geogr
Keenan JM (2020) COVID, resilience, and the built environment. Environ Syst Decis 40(2):216–221
Kihato CW, Landau LB (2020) Coercion or the social contract? COVID 19 and spatial (in)justice in African cities. City Soc 32(1)
Kraemer MUG, Yang CH, Gutierrez B, Wu CH, Klein B, Pigott DM, du Plessis L, Faria NR, Li R, Hanage WP, Brownstein JS, Layan M, Vespignani A, Tian H, Dye C, Pybus OG, Scarpino SV, Open C-DWG (2020) The effect of human mobility and control measures on the COVID-19 epidemic in China. Science 368(6490):493–497
Krzysztofik R, Kantor-Pietraga I, Spórna T (2020) Spatial and functional dimensions of the COVID-19 epidemic in Poland. Eurasian Geogr Econ
Kunzmann KR (2020) Smart cities after Covid-19: ten narratives. disP—Plann Rev 56(2):20–31
Mendes L (2020) How can we quarantine without a home? Responses of activism and urban social movements in times of COVID-19 pandemic crisis in Lisbon. Tijdschrift voor Economische en Sociale Geografie

Naddeo V, Liu H (2020) Editorial Perspectives: 2019 novel coronavirus (SARS-CoV-2): What is its fate in urban water cycle and how can the water research community respond? Environ Sci Water Res Technol 6(5):1213–1216
Pulighe G, Lupia F (2020) Food first: COVID-19 outbreak and cities lockdown a booster for a wider vision on urban agriculture. Sustainability (Switzerland) 12(12)
Qiu Y, Chen X, Shi W (2020) Impacts of social and economic factors on the transmission of coronavirus disease 2019 (COVID-19) in China. J Popul Econ
Saha J, Barman B, Chouhan P (2020) Lockdown for COVID-19 and its impact on community mobility in India: an analysis of the COVID-19 Community Mobility Reports, 2020. Child Youth Serv Rev 116:105160
Shammi M, Bodrud-Doza M, Towfiqul Islam ARM, Rahman MM (2020) "COVID-19 pandemic, socioeconomic crisis and human stress in resource-limited settings: a case from Bangladesh. Heliyon 6(5)
Sharifi A (2019a) Resilient urban forms: a macro-scale analysis. Cities 85:1–14
Sharifi A (2019b) Resilient urban forms: a review of literature on streets and street networks. Build Environ 147:171–187
Sharifi A (2019c) Urban form resilience: a meso-scale analysis. Cities 93:238–252
Sharifi A (2020) Urban resilience assessment: mapping knowledge structure and trends. Sustainability 12(15):5918
Sharifi A, Khavarian-Garmsir AR (2020) The COVID-19 pandemic: impacts on cities and major lessons for urban planning, design, and management. Sci Total Environ 749:
Sharifi A, Yamagata Y (2016) Principles and criteria for assessing urban energy resilience: a literature review. Renew Sustain Energy Rev 60:1654–1677
Sicard P, De Marco A, Agathokleous E, Feng Z, Xu X, Paoletti E, Rodriguez JJD, Calatayud V (2020). Amplified ozone pollution in cities during the COVID-19 lockdown. Sci Total Environ 735
Steele W (2020) Who governs Australia's metropolitan regions? Aust Planner
Teixeira JF, Lopes M (2020) The link between bike sharing and subway use during the COVID-19 pandemic: the case-study of New York's Citi Bike. Transp Res Interdiscip Persp 6
Thoi PT (2020) Ho Chi Minh City- the front line against COVID-19 in Vietnam. City Soc
Tian H, Liu Y, Li Y, Wu CH, Chen B, Kraemer MUG, Li B, Cai J, Xu B, Yang Q, Wang B, Yang P, Cui Y, Song Y, Zheng P, Wang Q, Bjornstad ON, Yang R, Grenfell BT, Pybus OG, Dye C (2020) An investigation of transmission control measures during the first 50 days of the COVID-19 epidemic in China. Science 368(6491):638–642
TNA (2012) Disaster resilience: a national imperative. National Academies Press
Wade L (2020) An unequal blow. Science 368(6492):700–703
Wasdani KP, Prasad A (2020) The impossibility of social distancing among the urban poor: the case of an Indian slum in the times of COVID-19. Local Environ 25(5):414–418
Xu H,. Yan M, Fu Q, Xiao K, Yu Y, Han D, Wang W, Cheng J (2020) Possible environmental effects on the spread of COVID-19 in China. Sci Total Environ 731
Yao Y, Pan J, Wang W, Liu Z, Kan H, Qiu Y, Meng X, Wang W (2020) Association of particulate matter pollution and case fatality rate of COVID-19 in 49 Chinese cities. Sci Total Environ 741

Chapter 17
Resilient Urban Housing Markets: Shocks Versus Fundamentals

Amine Ouazad

Abstract In the face of current challenges due to a pandemic, urban protests, an affordability crisis, and a series of other shocks to the quality of urban life, is the desirability of housing in dense urban settings at a turning point? Assessing the future of cities' long term trends remains an empirical question. The first part of this chapter describes the short-run dynamics of the housing market in 2020. Evidence from prices and price-to-rent ratios suggests expectations of resilience. Zip code-level evidence suggests a short-run trend towards suburbanization, and some impacts of urban protests on house prices. The second part of the chapter analyzes the long-run dynamics of urban growth between 1970 and 2010. It analyzes what, in such urban growth, is explained by short-run shocks as opposed to fundamentals such as education, industrial specialization, industrial diversification, urban segregation, and housing supply elasticity. This chapter's original results as well as a large established body of literature suggest that fundamentals are the key drivers of growth, and that the shocks considered in this paper have not had historically a measurable long-term impact on metropolitan population growth. The chapter illustrates this finding with two case studies: the New York City housing market after September 11, 2001; and the San Francisco Bay Area in the aftermath of the 1989 Loma Prieta earthquake. Both areas rebounded strongly after these shocks, suggesting the resilience of the urban metropolis.

Keywords Housing · Urban housing · Urban resilience · Urban growth

I would like to thank the Johns Hopkins Coronavirus Research Center, the Inter-university Consortium for Political and Social Research, Zillow, the OpenStreetMap Foundation, and Microsoft Research, for access to microdata. I would like to thank Ambika Gandhi for her careful comments on the manuscript.

A. Ouazad (✉)
Associate Professor of Economics, HEC Montreal 3000, Chemin de La Côte Sainte Catherine, Montreal H3T 2A7, QC, Canada
e-mail: amine.ouazad@hec.ca

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_17

17.1 Introduction

Between 55% (United Nations Population Division) and 85% (European Commission) of world population lives in urban areas. Such population is concentrated on a small share of the world's landmass: between 0.45% (Liu et al. 2014) and 1.5% (European Commission) depending on the estimates. The spatial concentration of location choices can be explained by agglomeration economies: a key mechanism that enables the description of the spatial distribution of location choices and economic activity using the tools of general equilibrium. The basic mechanisms of agglomeration economies were described as early as in Marshall's (1890) Principles of Economics, and are the essential ingredient in spatial models, including Fujita and Thisse (1996) and Behrens and Robert-Nicoud (2015). Agglomeration enables the sharing of common resources, the matching with potential employers, buyers, sellers, partners; it also enables learning and social interactions. Dense urban living makes workers more productive (Puga 2010). Agglomeration economics underpin the emergence and growth of cities (Duranton and Puga 2004). Efforts to estimate the magnitude of agglomeration economies are described in Rosenthal and Strange (2004), Melo et al. (2009) and Combes and Gobillon (2015).

Recent events have raised concerns that the benefits of agglomeration may be declining, affecting the desirability of urban living; perhaps even triggering an exodus from cities. The high density of urban setting suggests that, over long periods of time, the benefits of agglomeration have typically outstripped the costs of living in urban settings. These include traffic congestion (Duranton and Turner 2011), potential health hazards (Moore et al. 2003)[1], and labor poaching (Combes and Duranton 2006).

At least two shocks have affected urban areas in 2020: the Covid-19 pandemic and urban protests. Anecdotal evidence, statements by public officials as well as descriptive statistics suggest a positive correlation between urban density and the number of confirmed Covid-19 cases per capita.[2] In addition, urban protests focusing on racial justice have taken place in 43% of the 917 metropolitan areas in May 2020.[3] Thus, a key question is whether the multiple short-run shocks to urban housing markets are likely to cause a long-term decline in metropolitan population growth. Will advances in information technology coupled with the challenges of

---

[1]The causal impact of urbanization on health is ambiguous. For instance Singh and Siahpush (2014) displays a life expectancy that is 2.7 year longer in urban areas vs rural areas of the United States. Urbanization can lead to worse health outcomes in urban slums (Riley, Ko, Unger, Reis). While statistical correlations also suggest that urbanization is a necessary condition for growth, there are examples of urbanization without growth, e.g. in Sub-Saharan Africa and in South Asia (Annez and Buckley, Chapter 1 in Spence, Annez, Buckley, 2009; Chauvin, Glaeser, Ma, Tobio,).

[2]Table 17.1 presents regressions suggesting a statistically significant positive correlation between county population density and confirmed cases per capita.

[3]This statistic uses geocoded protest location data and Zillow's definition of metropolitan area boundaries. These data are described in Sect. 17.2.4.

living in dense neighborhoods lead to a decline of urban living, with a population living farther away from the densest cities? Or will cities remain either inherently or adaptively resilient (Rose 2014; Duranton et al. 2015) by following their long-run equilibrium path independently of even large short-run shocks? The answer is ultimately an empirical question, that can be informed by the analysis of (i) the nature of recent short-run *shocks* to local housing demand, and (ii) the importance of short-run shocks versus long-run *fundamentals* for the growth of metropolitan areas.

This chapter presents an analysis of the *short-run* shocks to the housing market in 2020 using Zip code-level housing data. As the long-term prospects of U.S. urban housing markets cannot yet be assessed, the chapter turns to the past to inform the future. The chapter performs an analysis of the *long-term* 1970–2010 growth trends of 306 metropolitan areas. It then presents two Zip-level case studies of the long-term resilience of New York City's housing market after September 11, 2001, and of the long-term resilience of the San Francisco Bay area after the 1989 Loma Prieta earthquake.

By combining micro data on Covid-19 infections, geocoded urban protests with census demographics, house prices, inventories, and rents, the chapter documents the large magnitude of the series of shocks that affected U.S. housing markets in 2020: prices, inventories, rents all experienced large movements. Yet, despite such large shocks, the dynamic of prices is consistent with the market's expectations of resilience. There is also evidence that, within metropolitan areas, housing demand is increasing faster in less dense neighborhoods and in neighborhoods farther away from the center of the metropolitan area. This is consistent with, at least in the short-run, households' adaptation to changing conditions by demanding housing in locations farther away from the impact of the short-run shocks.

The second part of the chapter uses longitudinal time series of census tracts with consistent 2010 boundaries to estimate the impact of fundamentals and shocks on population growth in 306 metropolitan areas.[4] Results suggest no statistically significant impact of shocks such as hurricanes and urban protests. This may be surprising given the experience of New Orleans. In 2018, the population was 16% lower than its pre-hurricane 2005 level. Yet, in other metropolitan areas, billion dollar events such as Hurricane Harvey and Hurricane Sandy had no discernible impact on metropolitan population levels. Beyond differences in the hydrology and topography of New Orleans, Houston, and New York, a set of economic differences in fundamentals may explain the divergent long-term paths in response to short-run shocks. This may also explain why Collins andr Margo (2007) finds a long-run impact of the 1967 Detroit riots (a short-run shock) on long-run population growth and on property values. Detroit's population peaked in 1950, 17 years before the riots. Glaeser (2011) argues that Detroit's industrial mono-culture may have hindered innovation. Hence, the shock of the riots may have been correlated with or

[4]Recent data includes information on more than 900 metropolitan areas. The 1970–2010 longitudinal data of the Neighborhood Change Database allows an analysis of 306 metropolitan areas.

driven by economic fundamentals such as Detroit's relatively lower industrial diversification and high level of racial segregation.

The chapter also presents a case study of the resilience of local housing markets in the aftermath of September 11, 2001 in New York. There is evidence of a short-run reversal of the gradient between price appreciation and distance to the Central Business District (CBD) during the September–December 2001 period. Yet the gradient returns to its prior, long-term, negative slope whereby price appreciation is higher in the CBD. There is no impact of the event on house price appreciation from 2002 onward. Similar findings emerge in this chapter's second case study, the impact of the 1989 Loma Prieta earthquake on San Francisco's housing markets. While there are visible population outflows in the 1990 Census in areas affected by the earthquake, there is no long term difference in population trends across areas with different earthquake risks. Large corporate headquarters have sprung up in those areas at risk of earthquakes. Overall the metro-level and the neighborhood-level evidence are consistent with the resilience of urban housing markets, whereby fundamentals drive metropolitan growth rather than short-run shocks.

This chapter's findings are consistent with prior literature. Davis and Weinstein (2002) documents the evolution of Japanese cities from the Stone Age to the modern era, with a specific focus on the impacts of World War II bombing on the growth of Japanese cities. They document a strong recovery in the years immediately after such an unprecedented shock to city population. Brakman et al. (2004) documents that this is also true of German cities strategically bombed during World War II: the impact on city growth is only temporary. Davis and Weinstein (2002) emphasizes the importance of locational fundamentals. This chapter emphasizes the importance of fundamentals such as education, industrial composition, and urban segregation. In other words, it can be argued that while resources such as coal or proximity to major streams may have determined the emergence of cities, it is their education levels, their diverse economic activity, and the opportunity to interact and learn that is the modern foundation of urban living.

This chapter's results also suggest that housing supply elasticity is a positive driver of metropolitan population growth. Limited housing supply elasticity in some metropolitan areas might be driving recent population outflows from California to more affordable housing markets in Texas, Arizona, Nevada, and other states. Zabel (2012) finds that the cost of housing is a driver of labor mobility across metropolitan areas during the 1990–2006 period. Limited housing supply elasticity may be hindering recovery after shocks. Koster et al. (2012) argue that planning policies may have hindered the rebuilding of bombed areas in Rotterdam after World War II.

Finally, this chapter's findings are also consistent with prior work on pandemics and housing markets. Francke and Korevaar (2020) finds only short-run impacts on house prices and rents of the 17th century plague in Amsterdam of 19th century cholera in Paris. These effects are short-lived as they do not last more than a year. These results are also consistent with the Canadian experience of the SARS pandemic. On April 23, 2003, the World Health Organization issued a travel advisory for Toronto recommending postponing all but essential travel. There is however no evidence of impacts of SARS infections on the growth of Toronto's housing markets (prices and transaction volumes) in 2003 and beyond. The Teranet index displays a 5% year-on-year house price increase throughout 2003. Price increases remain strong in subsequent years, reaching 7–9% between October 2007 and May 2008. This may be due to the relatively limited number of SARS cases in Toronto. This is also consistent with a model in which house prices capitalize the entire flow of future rents and thus are resilient in the face of short-run shocks such as pandemics.

Overall, the results described in this chapter imply that metropolitan areas may be on an equilibrium path, and that shocks are short run deviations from this single dynamic equilibrium. Davis and Weinstein (2008) finds no evidence of multiple equilibria in cities' dynamics, using data for 114 Japanese cities. This paper finds that industrial composition and the size of the manufacturing sector are unchanged after large shocks to city population and employment.

This chapter proceeds as follows. Section 17.2 describes the ongoing shocks experienced by U.S. housing markets since March 2020, and their impact on market dynamics. Section 17.3 describes long-run 1970–2010 evidence of the drivers of metropolitan population growth, as well as new evidence of the impact of September 11, and the 1989 Loma Prieta earthquake on neighborhood dynamics.

Section 17.4 provides a cautious forecast of urban resilience in the face of the 2020 shocks.

17.2 The U.S. Housing Market in 2020: Resilience and Adaptation

17.2.1 Short-Run Aggregate Dynamics: Insights from Prices and Rents

Time series of house prices, listings, and rents suggests that 2020 is a major shock to real estate dynamics. It also provides evidence about the market's expectation of resilience. We describe the dynamics using Zillow's time series data and interpret them using standard principles of real estate: while rents reveal the current flow value of housing, prices capitalize current *and* future flow values. This section uses metro-level time series. In the next section we focus on smaller, more granular, local housing market dynamics at the 5-digit ZIP code level.

Figure 17.1a presents the year-on-year change in the Zillow House Value Index (ZHVI) between January 31, 2015 and July 3, 2020. This price index is built using a repeat-sales methodology similar to Case and Shiller (1987). The bold line is for the United States, the dashed line for the tristate metropolitan area of New York; and the dotted line for the metropolitan area of Los Angeles. All three series suggest that after a deceleration of prices in 2019, transaction prices experienced an accelerating growth from January till July 2020. Perhaps surprisingly, such deceleration did not soften during the Covid-19 pandemic, but rather price growth accelerated, reaching year-on-year levels above 4% in July.

The dynamic of rents is rather different, and reconciling this apparently contradictory dynamics provides new insights. Figure 17.1b displays the year-on-year change in the Zillow Observed Rent Index (ZORI), which measures changes in asking rents over a sample of properties. By measuring rents for the same units, this index is akin to a "repeat-rent" index. Hence this index is built with a similar method as the house value index. The figure suggests that rent growth not only decelerated, but rents decreased in the metro area of New York, dropping by more than 2% year-on-year in July 2020. In the United States overall and in Los Angeles, rents are close to declining. Figure 17.1d presents the metro-level distribution of average year-on-year changes during the March to August 2020 period, for the 100 largest metropolitan areas. It suggests that overall prices have increased faster than rents, with a significant number of metropolitan areas experiencing rent declines or stagnation; while there is only one metro area with price declines.

Listings experience the largest drop. Figure 17.1c suggests that listings started decreasing significantly at the beginning of the pandemic, dropping year-on-year by 20% in the U.S. and by up to 40% in Los Angeles, with a rebound in June-July 2020. This presents a first hypothesis for the seemingly paradoxical increase in prices. A first hypothesis is selection bias. Houses that do not transact during a given time period do not contribute to a repeat sales index by construction, and houses in the lower part of the price distribution are more likely to experience no transaction during downturns (Ouazad and Rancière 2019). While houses that do transact experience price increases, houses whose value is declining might not contribute to the set of observations of the price index. Hence part of the index's fluctuations may simply be due to dynamic selection (Gatzlaff and Haurin 1997). This possibility nevertheless is unlikely to explain the observed price and rent trends. First, both the price index and the rent index are vulnerable to this selection bias. Second, one econometric approach to correcting for such selection bias, the inverse time weighting approach (Ambrose et al. 2015), does not typically yield significant differences in the price index.

Three alternative mechanisms rationalize the evolution of the housing market's trends. The simplest way to express them is using the Gordon and Shapiro (1956) approach. This approach capitalizes expected rents using a constant discount factor and a constant expected growth rate of rents. Rents are net of maintenance costs, property taxes, and potential credit costs. Formally,

$$\frac{R}{P} = r - g \tag{17.1}$$

where R is the current net rent, P the current value of the asset, r the required capital yield, and g the growth rate of net rents. This can be written as $p = \frac{R}{r-g}$, suggesting that prices may increase even as *current* rents fall whenever (i) the expected growth

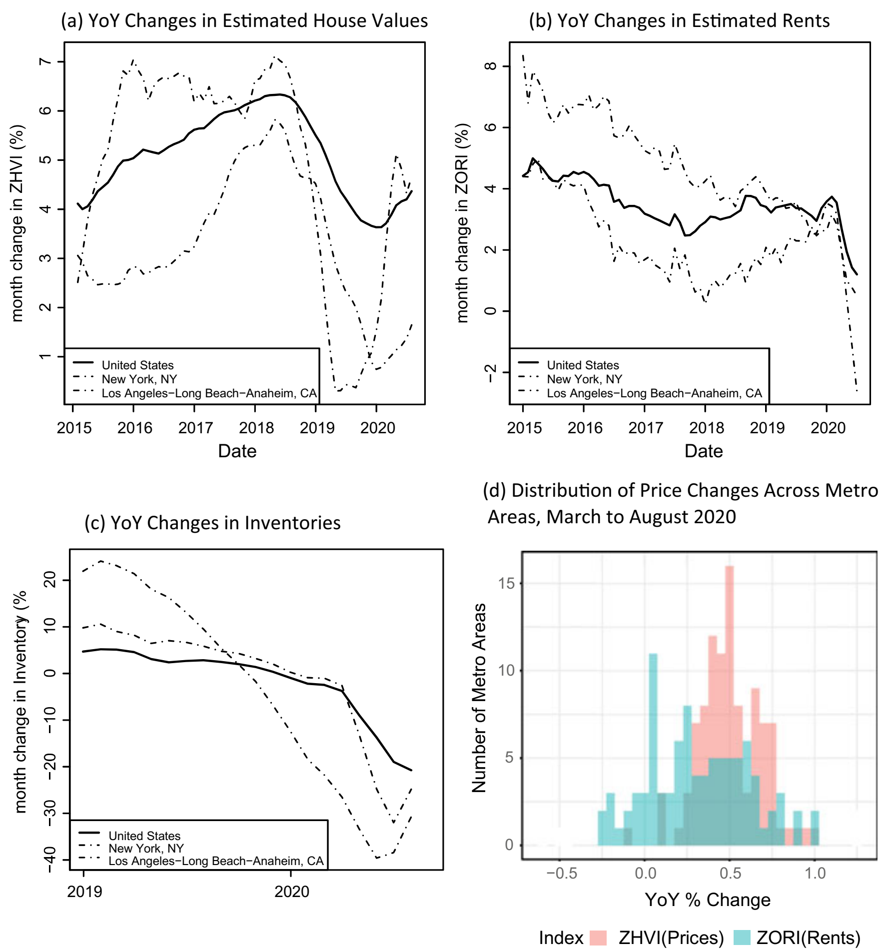

Fig. 17.1 The U.S. Housing Market in 2020: Aggregate Dynamics. Panels (**a**), (**b**), (**c**) provide simple statistics on year-on-year changes in house values, rents, and inventories for the US (bold line) and for the two largest metropolitan areas (dotted and dashed lines). Inventories are not available for the same time period as prices. Panel (**d**) presents two histograms of price changes in red (resp. rent changes in blue) for the 100 largest metropolitan areas

rate of rents increases, (ii) the rate of return r declines, (iii) net rents increase relative to gross rents due, for instance, to a decline in credit costs.

Figure 17.2a shows that as expected, the increase in prices and the decline of rents implies a declining rent-to-price ratio, which is the outcome of at least these three potential mechanisms. First, the decline in the 30-year fixed rate mortgage average (Fig. 17.2b) lowers interest costs and pushes prices up at given rents. The impact of cheap mortgage credit on house prices has been documented (Adelino et al. 2012; Favara and Imbs 2015; Justiniano et al.2019). Second, the decline in the

AAA corporate bond yield (Fig. 17.2c) suggests that prices are increasing in a search for yields. The required rate of return on capital can be approximated by such a safe bond yield plus a risk premium. Third, the increase in prices and the decline of the price-to-rent ratio is consistent with expectations of rent growth; while current rents may be low, buyers are arguably expecting substantial *future* rent growth. Figure 17.2d plots expectations of price and rent growth using the time series of Fannie Mae's National Housing Survey. While expectations of rent growth (g) fall sharply in June 2020, they rebound and become positive again in July 2020, suggesting that housing market participants expect a short-lived trough in rents rather than a prolonged slowdown.

17.2.2 Covid-19 Cases: Greater Frictions, Declining Rents, Resilient Prices

The global Covid-19 pandemic affected housing markets throughout the world. Yet, the spatial distribution of confirmed cases and deaths is uneven. The pandemic emerged in the United States as a significant measurable phenomenon in the first half of March 2020. While daily confirmed cases were below 70 a day on March 5th, they grew to a peak of more than 77,000 cases a day on July 16th 2020 for a total of 5.9 million cases as of August 29, 2020.[5] On the same day, Canada had reached a total confirmed number of cases of more than 129,000 cases.

Figure 17.3a presents the spatial distribution of cases per capita across Zillow's metropolitan housing markets. The colors corresponds to quantiles of cases per capita. This map suggests that Covid-19 infections reached most housing markets, with an average number of confirmed cases per 100 residents of between no confirmed case (three metros of Utah: Cedar City, Price, and Saint George) and a maximum of 9 cases per 100 residents (Alta, Indiana). As expected, the largest metropolitan areas host the largest number of total confirmed cases, with 543,000 cases in New York, 282,476 in Los Angeles. With the exception of Riverside, California, the largest numbers of cases are all in the 10 largest metropolitan areas by population.

Table 17.1 performs a county-level regression of confirmed cases per capita on a range of variables from the American Community Survey. Density is measured by the ratio of county population on the county's area in squared kilometers. The log density is a more relevant measure than density itself as the regression is less driven by extreme observations. The regression includes state fixed effects—results are unaffected by the inclusion of state fixed effects. The table displays an economically and statistically significant correlation between county log density and confirmed cases per capita regardless of the inclusion of additional controls.

[5]This chapter was written in September 2020.

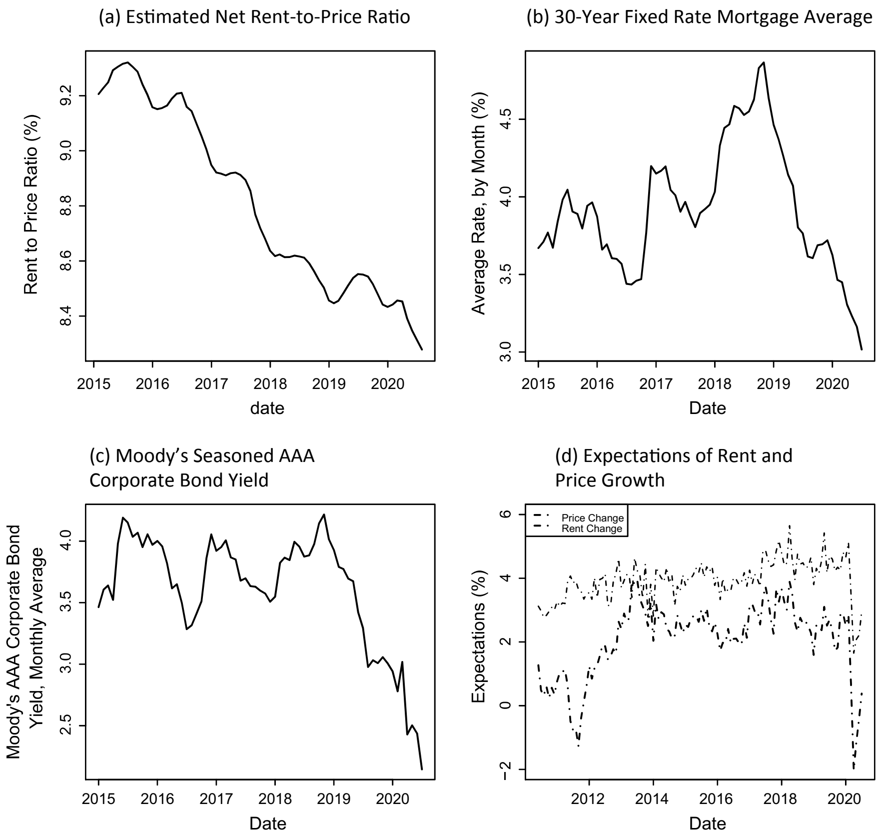

Fig. 17.2 The U.S. Housing Market in 2020: Explaining the Resilience of Prices. These graphs describe the decline in the rent-to-price ratio, net of maintenance costs and property taxes (Fig. **a**), and three key components of the Shapiro-Gordon valuation formula: **b** the 30 year fixed rate mortgage average, which measures credit costs and affects net rental yields; **c** the AAA corporate bond yield, a proxy for the yield on capital; and **d** expectations of rent growth. *Sources* Zillow ZHVI and ZORI for the rent-to-price ratio. Maintenance cost from Harding et al. (2007). Average property tax rate from Malm and Pomerleau (2015). Federal Reserve of St Louis series DAAA and MORTGAGE30US. Fannie Mae's July 2020 National Housing Survey

We match such cases by population to shifts in inventories to document a substantial and significant correlation between the decline in real estate inventories and the number of cases per population. This is depicted in Fig. 17.3b. The vertical axis is the average year-on-year percentage change in inventories over the March to August 2020 period. The horizontal axis is the number of cases per population, where the total number of confirmed cases is from the Johns Hopkins Coronavirus Research Center; and county-level population aggregated to Zillow's metro areas is

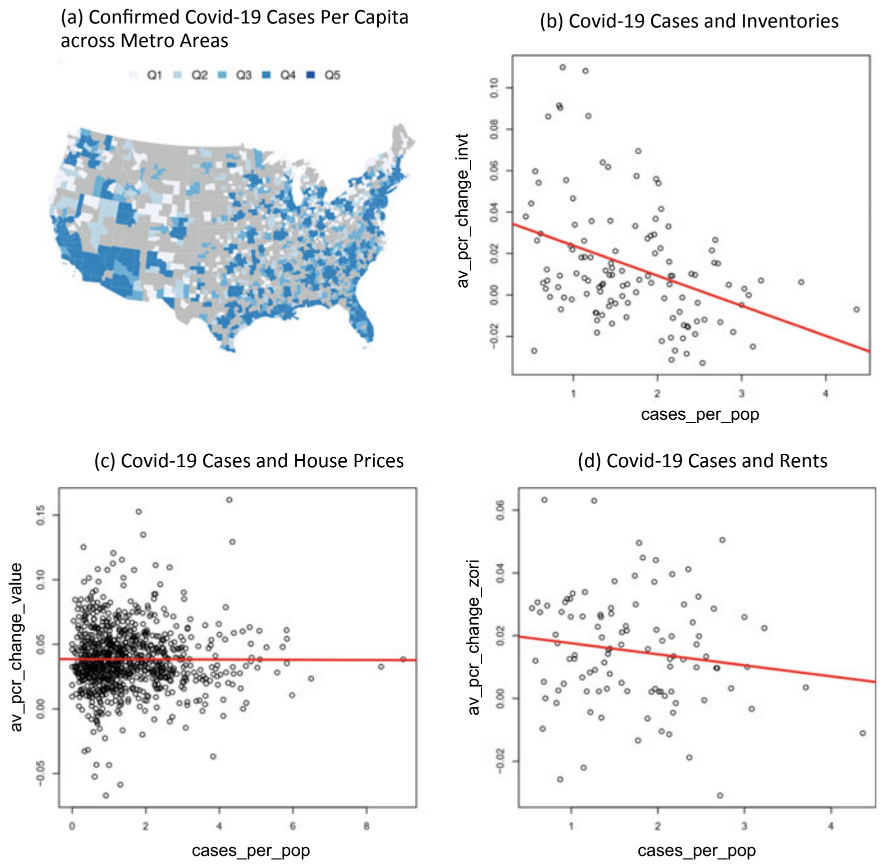

Fig. 17.3 The U.S. Housing Market in 2020: Covid-19 Infections and the Housing Market

from the 2018 American Community Survey.[6] The pandemic affected the ability of homeowners to sell and of buyers to acquire a property, likely increasing search frictions and leading to inefficiencies. There is no metropolitan area with cases per population above the median *and* inventory growth above the median. Charleston, South Carolina, with more than 3 cases per 100,[7] experienced a 4% decline in inventories. New Orleans, with 3.1 cases per 100, experienced a 3.7% decline in inventories. In contrast, some of the largest increases in inventories happened in metropolitan areas with low case numbers: San Francisco, with only 1.1 cases per 100, experienced a +3.2% increase in listings.

[6]While 2020 county-level population numbers have not yet been released, a similar correlation would arguably hold with updated data.

[7]Confirmed cases are also reported as cases per million. Using this alternative scaling does not affect this chapter's analysis.

Table 17.1 Confirmed Covid-19 cases per capita and county demographics

	Dependent Variable: Confirmed Covid-19 Cases Per Capita						
	(1)	(2)	(3)	(4)	(5)	(7)	(8)
log(Density)	0.13*** (0.01)		0.04* (0.02)	0.03* (0.02)	0 04** (0.02)	0.07*** (0.02)	0.07*** (0.02)
Median Age		−0.06*** (0.00)	−0.03*** (0.00)	−0,02*** (0.00)	−0.02*** (0.00)	−0.02*** (0.00)	−0.02*** (0.00)
log (Median household income)			−0.15 (0.09)	0.45** (0.15)	0.53*** (0.15)	0.64*** (0.16)	0.64*** (0.16)
Frac. Black			2.47*** (0.16)	2.37*** (0.16)	2.45*** (0.16)	2.47*** (0.17)	2.47*** (0.17)
Frac. Hispanic			3.31*** (0.18)	3.32*** (0.18)	3.00*** (0.19)	3.08*** (0.19)	3.08*** (0.19)
Frac. Asian			−0.88 (0.77)	−1.38 (0.77)	−1.20 (0.77)	−1.29 (0.79)	−1.29 (0.79)
Frac poverty				2.66*** (0.54)	1.75** (0.55)	1 44** (0.55)	1.44** (0.55)
Frac. no health coverage					2.73*** (0.38)	2.57*** (0.38)	2.57*** (0.38)
Frac owner occupied						−0.32 (0.30)	−0.32 (0.30)
Frac mobile home						1.60*** (0.27)	1.60*** (0.27)
Num. observations	3220	3220	3219	3510	3219	3219	3219
R^2 (full model)	0.38	0.42	0.51	0.51	0.52	0.53	0.53
Ft^2 (proj model)	0.03	0.10	0.23	0.24	0.25	0.26	0.26
Adj. R^2 (full model)	0.37	0.41	0.50	0.50	0.51	0.52	0.52
Adj. R^2 (proj model)	0.01	0.09	0.22 en	0.23	0.24	0.25	0.25
Num of State Fixed Effects	52	52	52	52	52	52	52

***$P < 0.001$; **$p < 0.01$; *$p < 0.05$

This table correlates county Covid-19 cases per capita with population density and Census demographics. Regressions include a state fixed effect

Sources County-level confirmed cases as of August 20, 2020, from the Johns Hopkins Coronavirus Research Center. County population and other demographic characteristics from the 2018 American Community Survey. Density is the ratio of ACS population over the area of the county in squared kilometers using the Census Bureau's boundary shapefile and the U.S. National Atlas 2163 projected coordinate reference system

There is no detectable metro-level correlation between house price dynamics and the number of confirmed cases, suggesting that the impact of the pandemic may be more likely to stem from the economic consequences of the pandemic rather than through the avoidance of infection probabilities. Figure 17.3c plots the average monthly change in prices for each of the largest 100 metros against the number of cases per population. It suggests that prices are largely unrelated to confirmed cases, with a large variance of up to 20 percentage points, in house price changes for metros with low infection numbers. And no significant difference between metros with low infection numbers and metros with high infection numbers.

Evidence may come from the correlation between rents and infection numbers. Figure 17.3d plots the average change in rents against the number of cases per population. Metro areas with large numbers of cases per population experienced lower than average rent growth. In contrast, metropolitan areas with low case counts per population experienced some of the largest rent growth levels. These three pieces of evidence (on inventories, prices, rents) suggest a substantial short-run impact of the pandemic on the flow utility of housing in metro areas affected by the pandemic, but a long-run expectation of resilience whereby the pandemic does not significantly affect buyers' expectations of the value of living in metro areas with large cases per population.

17.2.3 Evidence of Short-Run Suburbanization

While house prices are overall on the rise, there may be *within-city* shifts in demand towards neighborhoods that are less dense and farther away from the central business district, which are arguably less exposed to the pandemic. Anecdotal evidence[8] suggests that cities may become more resilient when households increase their demand for less dense areas where the propensity for infections is perceived to be lower.[9] To perform this analysis, we turn to neighborhood-level evidence from the New York City metro area.

Figure 17.4 presents the example of two neighborhoods with two extreme density levels. The upper panel (a) presents the Upper East Side, with a population density of 53,029 residents per squared kilometer as of 2018. It features condominium towers and other high density urban developments. Such density is higher than the average density of the densest cities in the world. This stands in contrast with New York's Great Neck Peninsula (lower panel (b)), on the northern side of Long Island, with a population density 18 times lower, of 2,968 residents per squared kilometer. While commuting time from Great Neck to downtown Manhattan is less than half an hour, this neighborhood has more than 20 parks across 9 villages, and features "verdant residential areas."[10]

[8]"New Yorkers Look To Suburbs and Beyond. Other City Dwellers May Be Next", National Public Radio, July 8, 2020. "New Yorkers Are Fleeing to the Suburbs: 'The Demand Is Insane'", New York Times, August 30, 2020.

[9]While many other factors than density explains the variance of cases across locations, there is a significant and positive correlation between population density and cases per capita, as displayed in Table 17.1. Marcelle Sussman Fischer, the New York Times, July 2016.

[10]See above footnote.

(a) Higher Density: The Upper East Side, ZIP 10075

(b) Lower Density: Russell Gardens, Great Neck Plaza, Great Neck Estates ZIP 11021

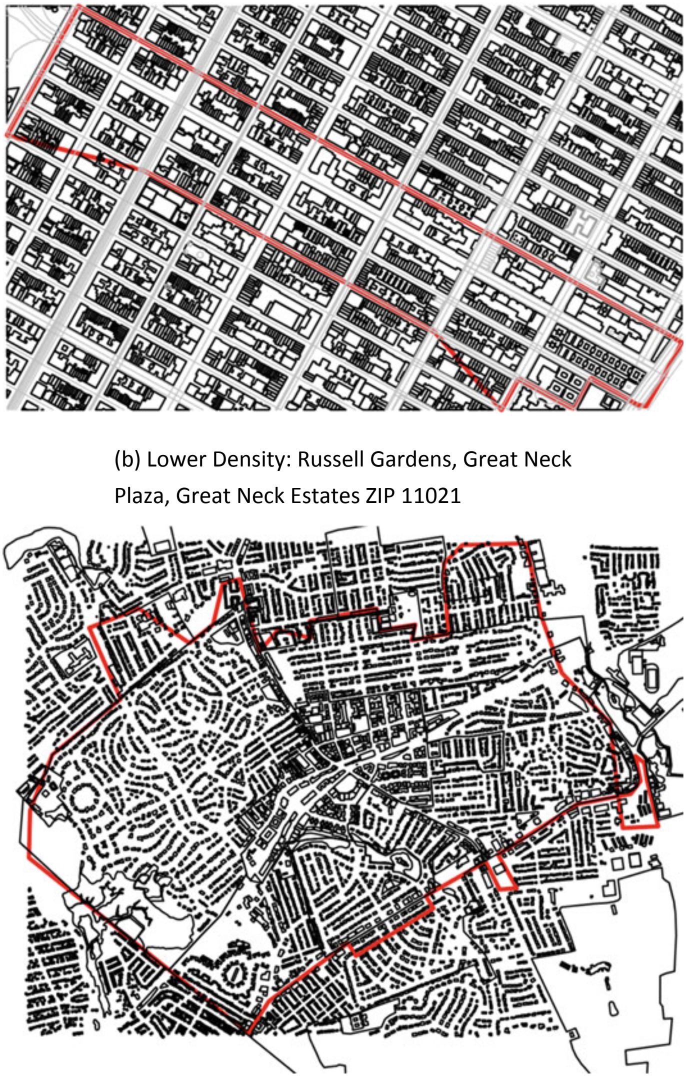

Fig. 17.4 Low- and High-Population Density ZIP Codes: Two Typical Examples. These two maps present the layout of buildings and roads in two sample ZIP codes. The ZIP code of the upper panel is part of New York's Upper East Side, with a high population density of 53,029 residents per squared kilometers, 18 times that of the ZIP of the lower panel. Such ZIP code includes the Great Neck Estates on the northern part of Long Island. It has a population density of 2,968 residents per squared kilometers. Maps have different scales. ZIP boundaries projected according to the Census 2010 boundaries. Building footprint and roads current as of 2020 from Open Street Map. Population counts from the 5-year averages of the 2018 American Community Survey

We test whether neighborhoods such as the Upper East Side have seen a decline in demand relative to neighborhoods such as Great Neck during the period of March to August 2020. We do so by regressing shifts in prices on (1) the distance to the population-weighted center of the metropolitan area, (2) population density, as the ratio of the 2018 ACS population over the area of the ZIP Code Tabulation Area in squared kilometers.

The results are presented in the scatter plot of Fig. 17.5 and in Table 17.2. These scatter plots and the regression table suggest a *reversal* in patterns of housing demand during the pandemic. Indeed, the correlation between house price appreciation and density is positive in the three months of March-May 2019. That is also true for other periods outside the pandemic. The correlation between house price appreciation and urban density is also positive in the same time period of 2019, one year before the pandemic. Yet these two correlations turn negative and significant at 1% in the three months of March to May 2020. As the supply of housing moves slowly in the short-run, fluctuations in house prices between March and August are likely a good measure of the shift in the demand for housing units, vacating less desirable locations, and searching for housing in more desirable locations. Hence correlations between the characteristics of neighborhoods and shifts in transaction prices are likely a relevant proxy for shifts in tastes. These results suggest that, in the short-run, household demand has adapted by shifting to less dense and more peripheral neighborhoods.

17.2.4 Local Housing Markets and the May 2020 Urban Protests

The year 2020 saw a second series of shocks affecting urban housing markets. Urban protests in response to alleged actions by the police started in May 2020 and quickly spread to a substantial number of U.S. metropolitan housing markets. Figure 17.6a presents the geographic location of the May 2020 protests with more than 100 participants according to the geocoded crowdsourcing of the Wikimedia foundation.[11] The spatial extent of these protests exceeds those of the 1968 protests as documented by Stanford University's Susan Olzak in her collection of *Ethnic Collective Action in Contemporary United States*. This suggests that the 2020 urban protests may be the largest protests in U.S. history. Whether protests lead to positive reforms that improve the desirability of urban living; or whether protests lower the quality of life in urban metros is an empirical question.

Collins and Margo (2007) uses decennial Census data between 1950 and 1980 to describe the long-term impact of the 1960s riots on property values. They suggest

[11]Other potential sources of recent geocoded data include the *Crowd Counting Consortium*. Further literature may focus on *Factiva*'s news archive as an alternative source of information on protests.

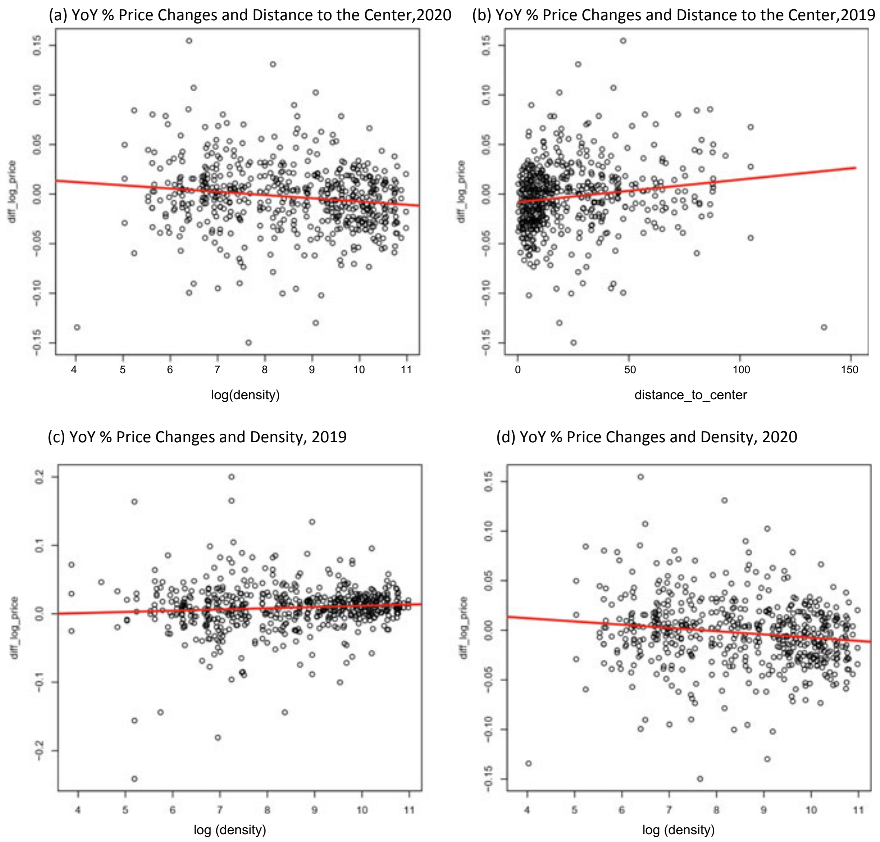

Fig. 17.5 The U.S. Housing Market in 2020: Evidence of Suburbanization

that riots led to a decline of property values, and in particular to a decline in black-owned property values, with no rebound in the 1970s. The perhaps most salient example of such decline is the city of Detroit. In this context, Glaeser and Gyourko (2005) argues that shocks may lead to a long decline in metropolitan areas as the supply curve of housing is L-shaped: a decline in housing demand may lead to a decline in house prices down to the marginal cost of housing, leading to larger vacancy levels, attracting lower productivity workers and lowering the benefits of agglomeration economies.

Figure 17.6b and c present a correlational analysis of urban protests and house prices in the metropolitan area of Los Angeles. Figure 17.6b presents evidence that George Floyd protests extended from the northern neighborhood of San Fernando to the southern neighborhoods of Laguna Niguel. Figure 17.6c compares house price appreciation in ZIP codes where a protest happened (red line) to house price appreciation in ZIP codes where a protest did not occur (black). While the hypothesis that the appreciation rates are parallel cannot be rejected statistically

Table 17.2 Within-City Adaptation: Short-Run Suburbanization in New York, March-July 2020

	Dependent	Variable: YoY Price	Appreciation
Time period	2015–2019	March–July 2019 March–July 2020	
(Intercept)	−1.116***	−0.622	2.523***
	(0.208)	(0.782)	(0.816)
log(density)	0.032	0.179**	−0.327**”
	(0.021)	(0.091)	(0.094)
Additional controls	Year fixed effects		
R^2	0.013	0.007	0.022
Adj. R^2	0.012	0.005	0.02
Num. obs.	13439	581	541
Time period:	Dependent variable: YoY Price Appreciation		
	2015−2019	March−July 2019 March−July 2020	
(Intercept)	0.750***	1.067***	−0.806***
	(0.102)	(0.204)	(0.211)
Distance to center (km)	−0.004***	−0.007	0.023***
	(0.001)	(0.005)	(0.006)
Additional controls	Year fixed effects		
R^2	0.013	0.003	0.024
Adj. R^2	0.013	0.001	0.022
Num. obs.	13439	581	541

***$P < 0.01$; **$p < 0.05$; *$p < 0.1$

This table uses the ZIP-month Zillow House Value Index (ZHVI) for the Zip codes of the New York-Newark-Jersey City, NY-NJ-PA Metropolitan Statistical Area to regress the year-on-year appreciation (in logs) on the distance to the center (upper panel) and the logarithm of population density (lower panel). The distance to the center is the kilometer distance from the centroid of the Zip code tabulation area to the central business district. Population density computed using the Census Bureau's 2018 American Community Survey and the 2010 boundaries of Census Zip code tabulation areas

prior to May 2020, the appreciation rate declines and *crosses* the appreciation rate of ZIP codes where a protest did not occur. Hence, while on average across the United States, house price increases suggest expectations of urban resilience, there is local evidence of some expectations of decline in specific neighborhoods affected by the urban protests. This may be driven by the shift of demand towards neighborhoods less exposed to risk.

The endogeneity of riots may cast doubt on the causal interpretation of such event studies that rely on a pre-post analysis of the impact of riots on urban growth and decline. DiPasquale and Glaeser (1998) finds support for a Beckerian mechanism in which protests are the outcome of a comparison between the opportunity cost of time and the potential cost of punishment, and consistent with evidence by Esteban and Ray (2011), the paper finds that ethnic diversity matters. In the case of Los Angeles in May 2020, evidence suggests significant differences in the demographics of Zips with urban protests and without urban protests.

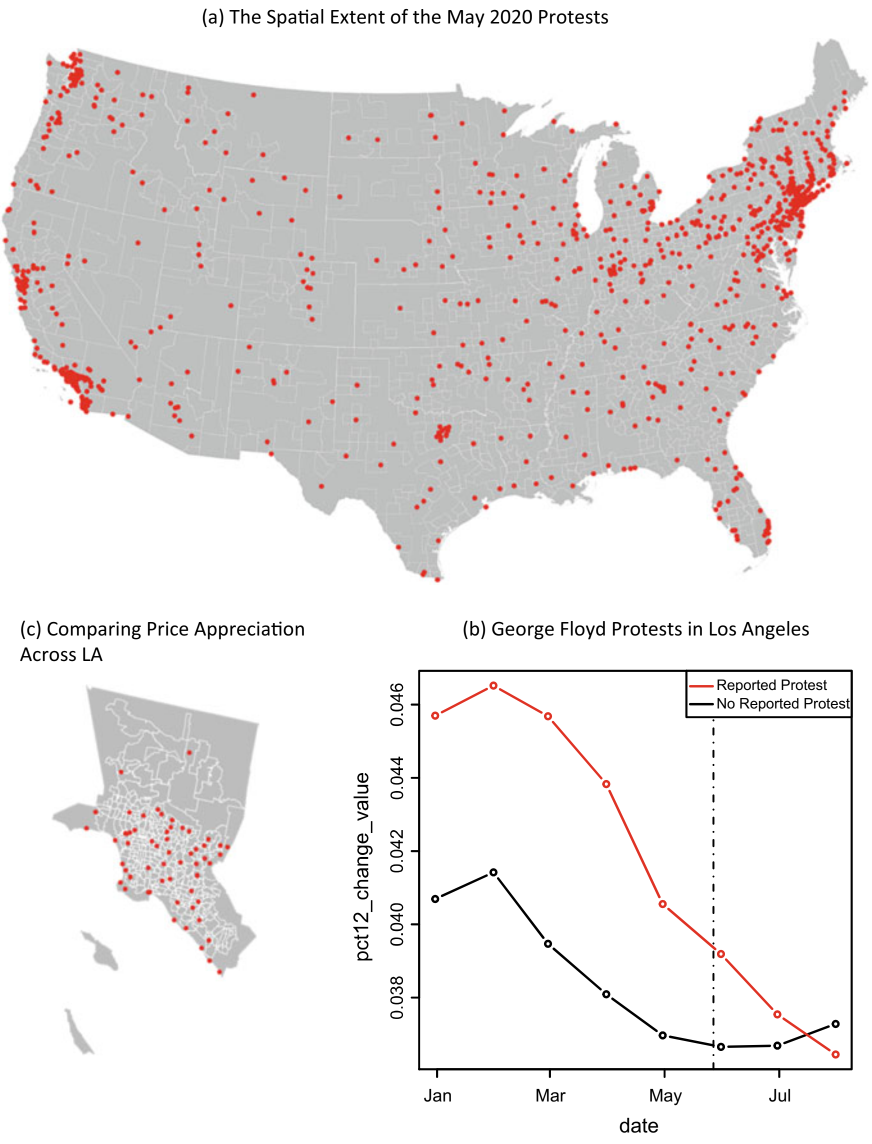

Fig. 17.6 The U.S. Housing Market in 2020: George Floyd Protests and Urban HousingMarkets. *Source* Crowdsourced May 2020 George Floyd protest data through the Wikimedia foundation

	Mean				
	Protest Zips	Other Zips	Difference	S.E.	t
Frac. African American	0.054	0.084	−0.029	(0.019)	−1.56
Frac. Hispanic	0.372	0.406	−0.034	(0.041)	−0.82
Frac. Asian	0.219	0.186	+0.032	(0.025)	+1.27
Frac. Owner Occupied	0.545	0.479	+0.066	(0.033)	+1.98
log(Median Household Income)	11.257	11.116	+0.141	(0.063)	+2.22
Frac. Poverty	0.124	0.154	−0.030	(0.016)	−1.82
Frac. No Health Coverage	0.113	0.133	−0.020	(0.012)	−1.70

In particular, this table suggests that protests occurred in neighborhoods that had significantly higher household income, lower shares of African Americans and Hispanics, higher shares of owner-occupied housing, lower poverty rates, and lower fractions of households with no health coverage. In the future, longer time series combined with sound identification strategies may allow for a causal analysis of the 2020 protests on urban housing markets.

17.3 Housing Markets in the Long Run: The Role of Shocks Versus Initial Conditions

The previous section described the short-run response of U.S. housing markets to the pandemic and the urban protests. The long-run prospect is yet unknown. The past can nevertheless inform our perception of future trends. This section describes the long-run evolution of metropolitan areas between 1970 and 2010 using longitudinal census tract data. It sheds light on the drivers of the rise and decline of cities. Are cities that experience large short-run shocks rebounding or are the typical impacts permanent shifts in population levels? Prior literature (Gabaix 1999; Ioannides and Overman 2003) has described the relative stability of city size distributions, which follow Zipf's law, where the log population is a linear relationship to the log rank of the metropolitan area. Yet, within such distribution, metro areas rise and fall. Understanding which observable characteristics drive such rise and fall is the focus of the first Sect. 17.3.1. While metropolitan area rankings tend to be stable, the desirability of specific neighborhoods within metropolitan areas changes more dramatically over time. This is the focus of Sects. 17.3.2 and 17.3.3. We present two case studies: the New York housing market in the aftermath of September 11; and the dynamic of San Francisco's neighborhoods after the 1989 Loma Prieta earthquake.

17.3.1 Explaining Metropolitan Growth in the Long Run

The relative ranking of metropolitan areas is stable over time: data from the *Neighborhood Change Database* suggests that the correlation between a metropolitan area's population rank in 1970 and its rank in 2010 is 0.8, implying that the best predictor of a city's future is its past. Rankings are also stable in other dimensions than population: Kerr and Robert-Nicoud (2020) shows that 1975–1980 annual patent count is a strong predictor of 2013–2018 patent count. Yet, some metropolitan areas experience rapid population shifts: the Dallas-Fort Worth-Arlington went from being the 11th most populous metro to the number 4 rank. The Atlanta metropolitan area went from the 19th to the 9th rank, joining the 10 largest metro areas. In contrast, Pittsburgh went down 13 notches, from the 9th most populous metro to the 22nd most populous, as the steel industry declined. Two of the largest relative growth levels were observed in Las Vegas, going from the 102nd to the 31st largest; and the Austin–Round Rock metropolitan area, jumping 58 spots to the 35th rank.

The largest relative decline is that of Johnstown, Pennsylvania going from the 150th to the 249th spot, with a 50.6% decline in population; this metropolitan area experienced three major floods, the most recent in 1977. This major flood could be a candidate for a causal driver of the city's decline. Another competing explanation for this decline is Johnstown's *specialization* in the steel industry, with steel mill plants in the heart of its downtown.

Hence, for Johnstown as for other metropolitan areas, a key question is whether shocks (here floods) or fundamentals (here industrial composition) explain their rise and fall? We use data from a range of sources to estimate the correlation between urban growth and (i) natural disasters, (ii) urban protests, (iii) industrial composition, (iv) education levels, (v) urban segregation, and (vi) housing supply elasticity. Each of these hypothesis has received support in the literature. The analysis of this chapter is not comprehensive, yet provides an overview of the potential drivers of urban growth and decline.

The "Shocks" Hypothesis:

- *Natural Disasters*

Natural disasters may cause either temporary or permanent shifts in population levels. We use data from NOAA's significant storm events, which provides damages and fatalities at the county level since January 1950. We count the number of billion dollar storms for each county in the 1970–2010 period. The metropolitan area with the largest number of such storms is the New Orleans–Metairie, LA core-based statistical area (CBSA), with 12 billion dollar storms. Then comes the Gulfport-Biloxi-Pascagoula, MS CBSA, with 6 such storms, and the Houston-The Woodlands-Sugar Land, TX CBSA, with also 6 such storms. The New Orleans CBSA is also the metropolitan area with the largest amount of billion dollar

Table 17.3 Explaining metropolitan growth in the long-run: shocks versus fundamentals

	Dependent variable: Change in metropolitan area population ranking, 1970−2010										
Fundamentals											
Black-white dissimilarity	−44.41** (15.89)										−47.15** (17.35)
% College		175.58*** (52.66)									87.64 (64.11)
Housing supply elasticity			9.79 (5.33)								9.36* (4.58)
Industrial composition											
% Mining & oil				0.06 (0.25)							0.12 (0.27)
% Construction				8.45*** (1.53)							5.44** (2.09)
% Manufacturing				0.33 (1.19)							−0.91 (1.80)
% Utilities				1.22 (2.45)							1.58 (3.19)
% Finance/RE				6.42** (2.11)							3.71 (2.59)
% Retail				1.33 (1.02)							3.30* (1.41)
Industrial specialization											
HHI Q2					−5.95 (6.31)						−4.70 (6.30)
HHI Q3					−12.02* (6.08)						−6.26 (7.56)
HHI Q4					−42.33***						−34.25**

(continued)

Table 17.3 (continued)

	Dependent variable: Change in metropolitan area population ranking, 1970−2010										
					(8.36)						(11.82)
Shocks											
A riot with damage to property						−2.54 (7.02)	−9.40 (10.43)				
Nbr of riots with damage to property							4.18 (4.70)				
Nbr of b$ storms								−0.02 (2.69)			
Property damages									−0.02 (0.81)		
Any b$ storm										−1.89 (10.79)	2.48 (10.37)
R^2	0.03	0.04	0.07	0.29	0.10	0.09	0.09	0.00	0.00	0.00	0.35
Num.Obs	306	306	306	306	306	306	306	306	306	306	306

This table presents a regression of the change in a metropolitan area's ranking between 1970 and 2010 on shocks and fundamentals. The shocks are (i) billion dollar storms according to NOAA's database of significant storm events, (ii) protests with damage to property. The fundamentals are black-white spatial segregation, education, housing supply elasticity, industrial composition, industrial diversification

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$

Sources NOAA's Storm Events Database, Ethnic Collective Action in Contemporary Urban United States, 1954-1992 (ICPSR 34341), County Business Patterns, the National Historical Geographic Information System tract level Census file of 1970 damages. We consider three variables explaining metropolitan growth: the number of events, the total property damages, and whether there was any event.

- *Urban Protests*

We test the urban protest hypothesis using data collected by Susan Olzak on Ethnic Collective Action in the United States (Olzak and West 1995). The list of events was compiled from the New York Times Index and from microfilms of New York Times articles. We focus on protests occurring between 1970 and the last date of the file, 1992. The data reports the number of protestors, the involvement of police, damage to property, the presence of non-residents, and other features, for each metropolitan area. We match the now deprecated Standard Metropolitan Area (SMSA) geographies to the 2010 Core Based Statistical Area, which is the most recent definition of metropolitan boundaries.

The "Fundamentals" Hypothesis:

We compare the impact of shocks to the impact of the following fundamentals: education, industrial composition, segregation, and housing supply elasticity. In each case, we describe the associated literature and the data used.

- *Industrial Composition*

Initial industrial composition may matter for long term metropolitan growth through a number of channels. First, specialization in industries with strong global demand for their products may lead to a greater demand for labor in the metropolitan area. This is the intuition of Bartik (1991) and Blanchard and Katz (1992).[12] Second, the diversity of industries initially present in a metropolitan area may foster the growth of a variety of industries that depend on an economic fabric of different suppliers and different customers. This is the industrial diversification hypothesis, perhaps most saliently popularized by Jane Jacobs in the Death and Life of Great American Cities: "*[t]ypically [small manufacturers] must draw on many and varied supplies and skills outside themselves, they must serve a narrow market at the point where a market exists, and they must be sensitive to quick changes in this market. Without cities they would simply not exist. […] City diversity itself permits and stimulates more diversity*." (Chapter 7, The Generators of Diversity).

We estimate the correlation between industrial composition (either specialization or diversification) using the earliest wave of publicly available data from the County Business Patterns. These data provide establishment numbers for each Standard Industrial Classification (SIC) 2-digit code. We aggregate such county level data to the boundaries of 2010 Core Based Statistical Areas, the same boundaries as those of the Neighborhood Change Database—this allows for measuring the growth of metropolitan areas. To test the specialization hypothesis, we use 2-digit SIC codes, leading to the following categories: Agriculture, Fishing and

[12]For a discussion of this empirical approach, see Goldsmith-Pinkham et al. (2018).

Forestry; Metal, Mining and Oil; Construction; Manufacturing; Transportation and Utilities; Finance, Insurance, and Real Estate; Non Classifiable; Retail. The measure of industrial specialization is the Herfindahl index (HHI), which is equal to the sum of the squares of the 2-digit SIC industry establishment shares:

$$HHI_m = \sum_k (Share_k)^2, \tag{17.2}$$

where m is the metropolitan area, k is the 2-digit SIC code, and $Share_k$ is the proportion of establishments in industry k. We use the share of establishments as this variable is well filled in the US Census Bureau's County Business Patterns. Given the large asymmetry and the fat tails of the *HHI* measure, results of the linear regression are more robust when regressing on four indicator variables for the four quantiles of HHI, from least specialized (Q1), to most specialized (Q4).

- *Education*

In Moretti (2012), the author describes the diverging paths of Menlo Park and Visalia, CA, and suggests that Menlo Park experienced significantly stronger growth thanks to its higher share of educated residents. In the *Rise of the Skilled City*, Glaeser and Saiz (2003) describes the higher growth of more educated cities, even after controlling for a range of covariates. This chapter's measure of education is the fraction of college graduates in 1970, according to the 1970 Census Count 4 Pa, provided by the National Historical Geographic Information System at the University of Minnesota.

- *Segregation and Inequality*

Our third measure of metropolitan area fundamentals is urban segregation. A number of papers suggest that urban racial segregation affects welfare. Li et al. (2013) argues that urban segregation has effects on metropolitan economic growth beyond its effects on minorities and poor residents. Thus urban segregation may be a concern for both distributional and efficiency reasons. Card and Rothstein (2007) suggests that neighborhood segregation has a consistently negative impact on the SAT scores of black students. Watson et al. (2006) describes the negative correlation between income segregation and metropolitan population growth.

We build a measure of Black–White urban segregation in 1970, at the beginning of our time period. The dissimilarity index measures the difference between the distribution of black residents across neighborhoods and the distribution of white residents across the same set of neighborhoods. We use 1970 census tract demographics. The dissimilarity index is a popular measure of segregation, notably developed in Duncan and Duncan (1955) and used in Cutler et al. (1999). The dissimilarity measure used in this paper is:

$$D_m = \frac{1}{2}\sum_j \left|\frac{w_{mj}}{w_m} - \frac{b_{mj}}{b_m}\right|, \tag{17.3}$$

where m is one of the 306 metropolitan areas, j indexes neighborhoods, $w_{m,j}$ (resp. $b_{m,j}$) is the number of white (resp. black) residents in neighborhood j, w_m (resp. b_m) the number of white (resp. black) residents in metropolitan area m. Results using other pairs of races and ethnicities are available from the author. Notable examples of segregated metropolitan areas include the Chicago-Naperville-Elgin, IL-IN-WI metropolitan area (0.90), Oklahoma City, OK (0.89), Los Angeles-Long Beach-Anaheim, CA (0.89), and Detroit-Warren-Dearborn (0.88). Alternative segregation indices such as the exposure or the normalized exposure indices (Cutler et al. 1999, Ouazad and Rancière 2016) provide different rankings, yet these three indices are strongly correlated.

- *Housing Supply Elasticity*

Our final hypothesis is that constraints on housing supply, stemming either from geographic or regulatory constraints, are a barrier to the development of metropolitan areas; they indeed constrain the growth of the housing stock (Mayer and Somerville 2000; Glaeser et al. 2006; Saks 2008), and make housing more expensive for productive workers whose productivity gains are transferred to the owners of land.

There is a variety of available housing supply elasticity measures, starting with Saiz (2010). We use recent metro-level elasticity measures from Gorback and Keys (2020), yet using Saiz's (2010) measures does not affect the regression estimates. We control for an indicator variable for a missing elasticity measure, as housing supply elasticity is typically not available for the smallest metropolitan areas.

- *Other possible fundamentals*

Other fundamentals could be included in a further analysis: innovations measured by the number of patents per capita (Kerr and Robert-Nicoud 2020), market access and transportation costs (Redding 2010), public transportation infrastructure (Gonzalez-Navarro and Turner 2018), the proximity to deep-water ports (Brooks et al. 2018), the flow of credit due to the structure of the banking sector in the metropolitan area (Clarke 2004; Ouazad and Rancière 2016), and other fundamentals.

Estimation Results: Shocks and Fundamentals:

Results of the analysis are presented in Table 17.3. The first columns present the covariates separately (education, industrial composition, segregation, elasticity, shocks), and the last columns performs the regression with all previous covariates simultaneously. In all 11 regressions the dependent variable is the change in the metropolitan area population rank between 1970 and 2010. A first notable fact is the strong correlation of black-white urban segregation, education, and industrial specialization, with a metropolitan area's relative growth. More segregated areas grow less than other, more integrated areas. Metropolitan areas with larger shares of college-educated residents grow significantly more. Areas with less diverse industrial composition (an HHI in the 4th quartile) tend to grow significantly less—

Table 17.4 After a shock: population changes in the San Francisco Bay Area after the 1989 Loma Prieta Earthquake

	Δ Census Tract log Population		
	1990–1980	2000–1990	2010–2000
(Intercept)	0.29*** (0.02)	0.16*** (0.01)	0.10*** (0.02)
% in liquefaction area	−0.12** (0.04)	−0.01 (0.03)	−0.01 (0.04)
R^2	0.01	0.01	0.01
Adj. R^2	0.01	0.01	0.01
Num. obs.	1,791	1.791	1. 791
	Δ Census Tract Population Rank		
	1990–1980	2000–1990	2010–2000
(Intercept)	7.81 (7.64)	−1.26 (6.61)	1.86 (9.2)
% in liquefaction area	−35.90* (18.01)	5.81 (15.59)	8.57 (21.69)
R^2	0.01	0.01	0.01
Adj. R^2	0.01	0.01	0.01
Num. obs.	1.791	1.791	1,791

***$P < 0.001$; **$p < 0.01$; *$p < 0.05$

These six regressions present the regression of decennial log population change (upper panel) and population rank (lower panel) on the share of a tract in an earthquake liquefaction area

Source California Department of Conservation's regulatory liquefaction maps. Neighborhood Change Database with 2010 Census Tract Boundaries

consistent with Jane Jacobs' hypothesis. Regressions indicate that it is the concentration in one or a few industries that predicts urban decline rather than the specialization in manufacturing.

Notably, none of the shocks—urban protests and storms—have a statistically significant impact at 5%. There is no significance whether one looks at the number of riots, whether there is any riot, the dollar amount of property damages due to storms, the number of storms, or whether there is any storm. In some cases the sign is as expected: a larger number of riots with damages to property has a negative impact on a metropolitan area's population growth; yet the impacts are not significant.

The last column includes all of the previous covariates simultaneously. Interestingly, both urban segregation and industrial specialization remain strongly significant (at 1%), again consistent with the central tenets of Jane Jacobs' the *Death and Life of Great American Cities*. Shocks remain non-significant. Perhaps notable is the significance of the housing supply elasticity measure: when controlling for other fundamentals, metropolitan areas with higher housing supply elasticities experience significantly higher growth (significant at 5%).

17.3.2 The Resilience of the New York City Housing Market After September 11

While city rankings by population size are stable, the ranking of neighborhoods tends to fluctuate substantially over time. Evidence from the Neighborhood Change Database suggests that the correlation between a tract's ranking in 1970 and the same population ranking in 2010 is only 0.2. This suggests that cities may be resilient when urban residents adapt their location and housing consumption by using the variety of amenities, housing stocks, and access to jobs to respond to shocks.

September 11, 2001 presents a case study for the impact of a terrorist event on the desirability of living in dense urban spaces. The event had dramatic consequences on the welfare of central New York City residents: Galea, et al. (2002) suggests that adults experienced symptoms consistent with post-traumatic stress disorder (PTSD), with a prevalence of PTSD up to 20% for those living south of Canal Street near the World Trade Center. In a set of respondents with an over-sampling of children neear the World Trade Center, Hoven et al. (2005) find that 29% of children experienced anxiety disorders.

This may have impacts on the New York housing market. In Israël, Elster, Zussman & Zussman et al. (2017) use hedonic and repeat sales approaches and show that attacks led to a 6 to 7% decline in house prices and rents. They also find that these effects are persistent beyond the 2000–2012 period, and suggest this is consistent with a perception of a continued threat. Bram et al. (2004) suggests that the September 11 events caused a sharp contraction of business activity. In the long run, Eisinger (2004) claims that "few lasting effects on city life are evident," and suggests that city dynamics are affected by long-term forces rather than even very significant short-term ones.

We provide quantitative neighborhood-level evidence of the dynamics of housing markets during and in the aftermath of September 11 using 5-digit ZIP code price data since 1996. We are thus able to estimate pre-existing trends, the impact of the events during the September to December 2001 period, and during the post 2001 period. We can also test whether these events affected the desirability of central city living in New York.

Evidence suggests a strong rebound of price growth in the October to December 2002 period compared to the October to December 2001 period. Monthly year-on-year price appreciation for the New York MSA as a whole and for the central New York City ZIP codes suggests that prices increased significantly a year after September 11 2001. There is no immediate discernible negative impact of September 11 on price appreciation in the New York MSA as a whole, suggesting that even shocks that a have strong negative impact on residents' welfare have not been capitalized into long run house prices.

Yet, Fig. 17.7 does present evidence that September 11 temporarily shifted demand away from central New York City and to the suburbs. Panel (a) shows that, before 2001, price appreciation is up to twice stronger in ZIP codes close to the central business district than for neighborhoods in the 10 to 60 km range (6 to 37 miles) from the central business district. This relationship is almost flipped in September and October 2001, where price appreciation is larger in ZIP codes farther away from the Central Business District (CBD) than close to it. Yet, panel (d) suggests this is only a temporary phenomenon, as price appreciation is again decreasing with the distance to the CBD between 2002 and 2020. This evidence suggests that while September 2001 did affect the demand for central New York residential housing, these effects did not last beyond 2001, at least in terms of price appreciation for residential units in the densest parts of New York.

The dramatic shock of September 2001 also affected the demand for central city residential housing in other cities. Abadie and Dermisi (2008) suggests that 9/11 increased Chicago's residents perception of the probability of terrorist attacks. They show that vacancy rates increased in the vicinity of the Sears Tower, the Aon Center, and the Hancock Center. This section's results do not, however, provide evidence of the long run impacts of these events on residential housing markets.

17.3.3 Rebuilding San Francisco After the 1989 Loma Prieta Earthquake

The Loma Prieta earthquake was an earthquake of magnitude 6.9 on the Richter scale that shook the San Francisco Bay area on October 17, 1989. According to the California Department of Conservation, it caused 63 fatalities, 3,737 injuries, and 6 billion dollars in property damage. Its epicenter was only 32.5 miles from Cupertino and 48 miles from Menlo Park, both of which were—and still are—major centers of technological innovation.

A study published in the years following the earthquake (Murdoch et al. 1993) analyzed the dynamic of house prices in six counties that were affected. The study used all residential home sales between January 1988 and November 1990. Results controlling for a substantial range of covariates suggested that the disaster caused an overall decline in property values as well as a gradient between house prices and measures of earthquake risk such as soil type and seismic zone designation. Yet, a key question is whether these price declines persisted and whether local amenities were affected in the long run.

In this last section, we perform an analysis of the long-run impact of the earthquake on neighborhood level population flows using data from the California Conservation Department[13] on earthquake risk, and data from the Neighborhood Change Database. In a first step, we estimate the liquefaction risk for each block of the San Jose-San Francisco-Oakland Combined Statistical area. According to the Geological Survey, liquefaction takes place "when loosely packed, water-logged sediments at or near the ground surface lose their strength in response to strong

[13]CGS Information Warehouse: Regulatory Maps.

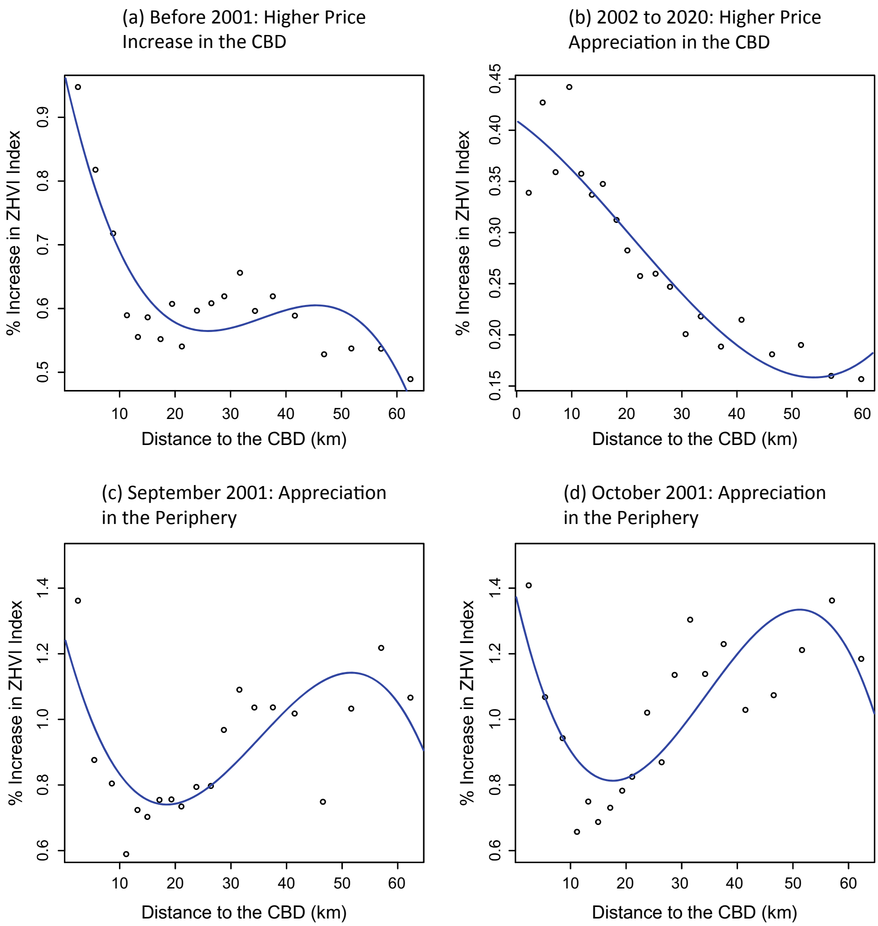

Fig. 17.7 Within-City Adaptation to Shocks: Short-Run Suburbanization in NYC In September–December 2001. These four graphs present the average price appreciation (using the ZHVI index) for bins of neighborhoods ordered by their distance to the Central Business District of the New York metropolitan area. Figures **b** and **c** suggest that the relationship changed sign, before going back to the average negative gradient observed prior to September 11. Zip-level ZHVI index from Zillow. Appreciation is month to month in this graph

ground shaking."[14] Liquefaction risk is a predictor of damage to structures (Cubrinovski et al. 2011; Towhata et al. 2016) as the nature of the soil leads to greater impacts on land at a given earthquake magnitude.

In a second step, we matched such block-level liquefaction data with the Neighborhood Change Database's tract level population levels. We compute the

[14] "What is liquefaction?", Natural Hazards, U.S. Geological Survey.

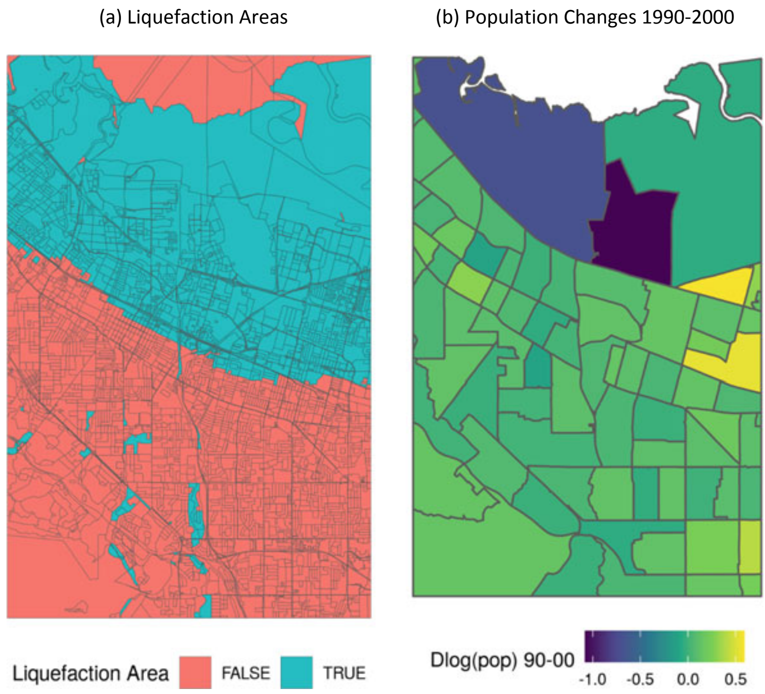

Fig. 17.8 Within-City Adaptation to Shocks: The SF Bay Area After the 1989 Loma Prieta Earthquake. Table 17.4 showed that liquefaction areas, while losing population compared to the rest of the metropolitan area between 1980 and 1990, display no significantly different population growth trend in the next decades (90s and 2000s). These two maps show that indeed, population growth in 1990–2000 in Mountain View is not discontinuous at the border of the liquefaction area. *Source* California Department of Conservation's regulatory liquefaction maps (left), matched to 2010 Census blocks. Geolytics Neighborhood Change Database 1990–2000 at the tract level (right)

share of a tract's area that is in the liquefaction area. Prices are harder to analyze over such a long period; nevertheless, population levels are an indicator of the immediate impact of the earthquake on living conditions, and long-term population changes are an indicator of the quality of neighborhood amenities. Owens et al. (2020) argue that neighborhood population levels can decline below a threshold that yields large amounts of vacancies.

Table 17.4 indeed suggests that population declined significantly in the immediate aftermath of the earthquake. Census data was collected in 1990, only a few months after the earthquake that shook the metropolitan area in October 1989. The first column of the upper panel of the table suggests that population declined 12% between 1980 and 1990 in tracts that are entirely in the liquefaction area. This is significant at 1%. The first column of the lower panel provides the regression where the dependent variable is the tract's population rank. A tract within the liquefaction area lost 35.9 ranks on average in 1990. Columns 2 and 3 nevertheless suggest that the effect of the earthquake is relatively short-lived: tracts in the liquefaction area experience no different population growth in the two decades following the devastating earthquake. There is no straightforward evidence that the earthquake is a major long-term driver of population dynamics.

This is also clear in Fig. 17.8, which focuses on Mountain View. While a substantial share of Mountain View is in the liquefaction area, including the headquarters of Google at 1600 Amphitheatre Parkway, there is no discernible impact of the liquefaction area on population dynamics. In other words, a regression discontinuity design at the boundary of such an area would likely yield no significant impact. This suggests that the 1989 Loma Prieta earthquake, with damages estimated to 6 billion dollars (Stover and Coffman 1993), had only a minor impact on the San Francisco Bay Area's long term population trend.

17.4 Conclusion

The total magnitude and the length of both the Covid-19 pandemic and the urban protests are, at the time of writing this chapter, yet unknown. The past can nevertheless provide a sliver of hope for the future. The evidence and the literature presented in this chapter suggest that, over the span of four decades, metropolitan areas are remarkably resilient to shocks—fundamentals rather than short-run shocks drive long-run population trends. Such resilience of urban housing markets suggests that the benefits of agglomeration play a key role in residents' welfare; sharing, matching, and learning are key motives that explain the desirability of urban living. These benefits have, over the long run, arguably been greater than the negative externalities of agglomeration. High levels of education, a diversified industrial composition, and racially integrated neighborhoods are keys to the resilience of metropolitan areas.

Disclaimer: The views and opinions expressed in this article are those of the individual authors and not those of the U.S. Federal Reserve Bank.

References

Abadie A, Dermisi S (2008) Is terrorism eroding agglomeration economies in central business districts? lessons from the office real estate market in downtown chicago. J Urban Econ 64 (2):451–463

Adelino M, Schoar A, Severino F (2012) Credit supply and house prices: evidence from mortgage market segmentation. Technical report, National Bureau of Economic Research

Ambrose BW, Coulson NE, Yoshida J (2015) The repeat rent index. Rev Econ Stat 97(5):939–950

Bartik TJ (1991) Who benefits from state and local economic development policies?

Behrens K, Robert-Nicoud F (2015) Agglomeration theory with heterogeneous agents. In: Handbook of regional and urban economics, vol. 5. Elsevier, pp 171–245

Blanchard OJ, Katz LF (1992) Regional evolutions. In: Brookings papers on economic activity, economic studies program. Brookings Inst:23(1)
Brakman S, Garretsen H, Schramm M (2004) The strategic bombing of German cities during World War II and its impact on city growth. J Econ Geogr 4(2):201–218
Bram J, Haughwout A, Orr J (2004) Has September 11 affected New York City's growth potential?. In: Modeling spatial and economic impacts of disasters. Springer, pp 53–73
Brooks L, Gendron-Carrier N, Rua G (2018) The local impact of containerization
Card D, Rothstein J (2007) Racial segregation and the black–white test score gap. J Public Econ 91 (11–12):2158–2184
Case KE, Shiller RJ (1987) Prices of single family homes since 1970: New indexes for four cities. Technical report, National Bureau of Economic Research
Clarke MZ (2004) Geographic deregulation of banking and economic growth. J Money Credit Bank:929–942
Collins WJ, Margo RA (2007) The economic aftermath of the 1960s riots in American cities: Evidence from property values. J Econ Hist:849–883
Combes PP, Duranton G (2006) Labour pooling, labour poaching, and spatial clustering. Reg Sci Urban Econ 36(1):1–28
Combes PP, Gobillon L (2015) The empirics of agglomeration economies. In: Handbook of regional and urban economics, vol. 5, Elsevier, pp 247–348
Cubrinovski M, Bray JD, Taylor M, Giorgini S, Bradley B, Wotherspoon L, Zupan J (2011) Soil liquefaction effects in the central business district during the February 2011 Christchurch earthquake. Seismol Res Lett 82(6):893–904
Cutler DM, Glaeser EL, Vigdor JL (1999) The rise and decline of the American ghetto. J Polit Econ 107(3):455–506
Davis DR, Weinstein DE (2002) Bones, bombs, and break points: the geography of economic activity. Am Econ Rev 92(5):1269–1289
Davis DR, Weinstein DE (2008) A search for multiple equilibria in urban industrial structure. J Reg Sci 48(1):29–65
DiPasquale D, Glaeser EL (1998) The Los Angeles riot and the economics of urban unrest. J Urban Econ 43(1): 52–78
Duncan OD, Duncan B (1955) A methodological analysis of segregation indexes. Am Sociol Rev 20(2):210–217
Duranton G, Henderson V, Strange W (eds) (2015) Resilience to climate shocks. In: Handbook of regional and urban economics. Elsevier
Duranton G, Puga D (2004) Micro-foundations of urban agglomeration economies. In: Handbook of regional and urban economics, vol. 4, Elsevier, pp 2063–2117
Duranton G, Turner MA (2011) The fundamental law of road congestion: Evidence from us cities. Am Econ Rev 101(6):2616–2652
Eisinger P (2004) The American city in the age of terror: a preliminary assessment of the effects of september 11. Urban Aff Rev 40(1):115–130
Elster Y, Zussman A, Zussman N (2017) Rockets: The housing market effects of a credible terrorist threat. J Urban Econ 99:136–147
Esteban J, Ray D (2011) Linking conflict to inequality and polarization. Am Econ Rev 101(4): 1345–74
Favara G, Imbs J (2015) Credit supply and the price of housing. Am Econ Rev 105(3):958–992
Francke M, Korevaar M (2020) Housing markets in a pandemic: Evidence from historical outbreaks
Fujita M, Thisse J-F (1996) Economics of agglomeration. J Jpn Int Econ 10(4):339–378
Gabaix X (1999) Zipf's law for cities: an explanation. Q J Econ 114(3):739–767
Galea S, Ahern J, Resnick H, Kilpatrick D, Bucuvalas M, Gold J, Vlahov D (2002) Psychological sequelae of the September 11 terrorist attacks in New York City. N Engl J Med 346(13):982–987
Gatzlaff DH, Haurin DR (1997) Sample selection bias and repeat-sales index estimates. J Real Estate Finance Econ 14(1–2):33–50

Glaeser E (2011) Triumph of the city: how our greatest invention makes us richer, smarter, greener, healthier and happier
Glaeser EL, Gyourko J (2005) Urban decline and durable housing. J Polit Econ 113(2):345–375
Glaeser EL, Gyourko J, Saks RE (2006) Urban growth and housing supply. J Econ Geogr 6(1):71–89
Glaeser EL, Saiz A (2003) The rise of the skilled city. Technical report, National Bureau of Economic Research
Goldsmith-Pinkham P, Sorkin I, Swift H (2018) Bartik instruments: What, when, why, and how. Technical report, National Bureau of Economic Research
Gonzalez-Navarro M, Turner MA (2018) Subways and urban growth: Evidence from earth. J Urban Econ 108:85–106
Gorback CS, Keys BJ (2020) Global capital and local assets: House prices, quantities, and elasticities. Technical report, National Bureau of Economic Research
Gordon MJ, Shapiro E (1956) Capital equipment analysis: the required rate of profit. Manag Sci 3 (1):102–110
Harding JP, Rosenthal SS, Sirmans C (2007) Depreciation of housing capital, maintenance, and house price inflation: Estimates from a repeat sales model. J Urban Econ 61(2):193–217
Hoven CW, Duarte CS, Lucas CP, Wu P, Mandell DJ, Goodwin RD, Cohen M, Balaban V, Woodruff BA, Bin F et al (2005) Psychopathology among new york city public school children 6 months after september 11. Arch Gen Psychiatry 62(5):545–551
Ioannides YM, Overman HG (2003) Zipf's law for cities: an empirical examination. Reg Sci Urban Econ 33(2):127–137
Justiniano A, Primiceri GE, Tambalotti A (2019) Credit supply and the housing boom. J Polit Econ 127(3):1317–1350
Kerr W, Robert-Nicoud F (2020) 'Tech clusters'. J Econ Perspect 34(3)
Koster HR, van Ommeren J, Rietveld P (2012) Bombs, boundaries and buildings: a regression-discontinuity approach to measure costs of housing supply restrictions. Reg Sci Urban Econ 42(4):631–641
Li H, Campbell H, Fernandez S (2013) Residential segregation, spatial mismatch and economic growth across us metropolitan areas. Urban Stud 50(13):2642–2660
Malm L, Pomerleau K (2015) Comments on who pays? a distributional analysis of the tax systems in all 50 states. Fiscal Fact No 447
Marshall A (1890) The principles of economics. MacMillan, London
Mayer CJ, Somerville CT (2000) Residential construction: Using the urban growth model to estimate housing supply. J Urban Econ 48(1):85–109
Melo PC, Graham DJ, Noland RB (2009) A meta-analysis of estimates of urban agglomeration economies. Reg Sci Urban Econ 39(3):332–342
Moore M, Gould P, Keary BS (2003) Global urbanization and impact on health. Int J Hyg Environ Health 206(4–5):269–278
Moretti E (2012) The new geography of jobs. Houghton Mifflin Harcourt
Murdoch JC, Singh H, Thayer M (1993) The impact of natural hazards on housing values: the loma prieta earthquake. Real Estate Econ 21(2):167–184
Olzak S, West E (1995) Ethnic collective action in contemporary urban US
Ouazad A, Rancière R (2016) Credit standards and segregation. Rev Econ Stat 98(5):880–896
Ouazad A, Rancière R (2019) Market frictions, arbitrage, and the capitalization of amenities. In: NBER Working Paper (w25701)
Owens III R, Rossi-Hansberg E, Sarte PD (2020) Rethinking detroit. Am Econ J Econ Policy 12 (2):258–305
Puga D (2010) The magnitude and causes of agglomeration economies. J Reg Sci 50(1):203–219
Redding SJ (2010) The empirics of new economic geography. J Reg Sci 50(1):297–311
Rose A (2014) Economic resilience and the sustainability of cities in the face of climate change: an ecological economics framework. In: Elgar companion to sustainable cities. Edward Elgar Publishing

Rosenthal SS, Strange WC (2004) Evidence on the nature and sources of agglomeration economies. In: Handbook of regional and urban economics, vol. 4. Elsevier, pp 2119–2171
Saiz A (2010) The geographic determinants of housing supply. Q J Econ 125(3):1253–1296
Saks RE (2008) Job creation and housing construction: constraints on metropolitan area employment growth. J Urban Econ 64(1):178–195
Singh GK, Siahpush M (2014) Widening rural–urban disparities in life expectancy, us, 1969–2009. Am J Prev Med 46(2):e19–e29
Stover CW, Coffman JL (1993) Seismicity of the United States, 1568–1989 (revised). US Government Printing Office
Towhata I, Yasuda S, Yoshida K, Motohashi A, Sato S, Arai M (2016) Qualification of residential land from the viewpoint of liquefaction vulnerability. Soil Dyn Earthq Eng 91:260–271
Watson T, Carlino G, Ellen IG (2006) Metropolitan growth, inequality, and neighborhood segregation by income [with comments]. In: Brookings-wharton papers on urban affairs, pp 1–52
Zabel JE (2012) Migration, housing market, and labor market responses to employment shocks. J Urban Econ 72(2–3):267–284

Chapter 18
Mutual Aid in the Time of COVID-19 and the Future of Hyper-Local Community Resilience

Greg Lindsay and Thea Koper

Abstract The COVID-19 pandemic has inspired the emergence of mutual aid groups across the United States. Popularized by the philosopher Peter Kropotkin, "mutual aid" refers to the voluntary exchange of resources and services for mutual benefit. In this century, mutual aid is more commonly identified with community-led recovery efforts in the wake of natural disasters. Post-pandemic mutual aid groups are notable due to their locally-isolated nature, use of digital tools and networks as a first resort, and the possibility of building more durable organization for future crises. This chapter provides a snapshot of post-pandemic mutual aid efforts, highlights their unique features, raises questions about their use of technology, and suggests future trajectories of these groups in the face of diminished government capacity and mounting natural and economic disasters.

Keywords Mutual aid · Hyper-local · Community-led recovery · COVID-19 recovery

18.1 Introduction

One consequence of the COVID-19 pandemic has been the spontaneous emergence of mutual aid groups across the United States. Popularized by the philosopher Peter Kropotkin a century ago, "mutual aid" refers to the voluntary exchange of resources and services for mutual benefit (Kropotkin 1902). In this century, mutual aid is commonly identified with community-led recovery efforts in the wake of natural disasters such as Hurricane Katrina (2005) and Superstorm Sandy (2012).

G. Lindsay (✉)
Applied Research, NewCities, Montréal, QC, Canada
e-mail: greg.lindsay@newcities.org

T. Koper
Munk School of Global Affairs and Public Policy, University of Toronto, Toronto, Canada
e-mail: thea.koper@mail.utoronto.ca

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_18

Post-pandemic mutual aid groups are notable in several respects. First, while COVID-19 is not limited to local constraints and impacts, government-mandated lockdowns and quarantines shattered existing spatial frames of reference. “Local” ceased referring to physically-accessible goods and services and shrank to the contours of one’s immediate shelter. Second, for this reason, contagion necessitated the use of digital tools and networks to both reinforce and establish connections in this new hyper-local context. Ranging in complexity from telephone numbers to Slack channels and Google docs, these free applications were essential to the rapid organization and scaling of new groups. But, they also raise questions about the sustainability, security, and equity of such platforms. To that end, civic tech non-profits such as Code for America and U.S. Digital Response have supported mutual aid groups in addition to government clients. Finally, while post-disaster mutual aid groups tended to splinter and/or contract following the event, the pandemic’s unprecedented scale and duration poses possibilities to build more persistent and replicable organizations.

This chapter aims to provide a snapshot of post-pandemic mutual aid efforts by highlighting their unique features and by raising questions about their use of technology. Therein, we suggest future trajectories of these groups in the face of diminished government capacity and mounting natural and economic disasters. We interviewed mutual aid network organizers and members, legal scholars, technology ethnographers, and executives of Code for America and U.S. Digital Response to supplement media reports and scholarly articles.

18.2 Origins of Mutual Aid

The term “mutual aid” first appeared in the essays comprising Peter Kropotkin’s *Mutual Aid: A Factor of Evolution.* Kropotkin’s (1902) view was that cooperation, not competition, is what historically allowed for both animal and human societies to flourish and persevere. While the term stems from Kropotkin’s twentieth century writings, the practice itself is rooted in the earliest human groups and societies. Kujala and Danielsbacka (2018) underline the evolutionary origins of reciprocity and the fundamental role it played (and still plays) in traditional societies as well as the modern welfare state. Voluntarily acting with empathy and care towards another person “promotes mutual trust and reciprocity”, and while the notion of reciprocity is perhaps best understood at the interpersonal level, it also manifests at the modern state level between governments and citizens (Kujala and Danielsbacka 2018, p. 2). The notion of mutual aid as solidarity rather than charity not only influenced the well-known social and political movements of the twentieth century, such as the Black Panther Party (which established the practice as one of their main avenues for political engagement and opposition during the 1960s), but also characterized the social networks of many immigrant groups that settled in United States cities in the late nineteenth and early twentieth centuries (Slavin 2020).

Dean Spade notes the turning point in mutual aid's recent history "was the rise of non-profitization, of specialization in social justice, the criminalization of a lot of those movements, [and] the increased regulation […] in the US that [made] mutual aid become less visible as a key movement tactic" (2020a, b). While mutual aid in the form of political opposition became less mainstream, it did not disappear. The work of mutual aid groups continues today in many different forms—from prison abolition, anticapitalist groups, and other social justice networks to more recent post-disaster groups.

Notable examples of post-disaster mutual aid groups include Hurricane Katrina's Common Ground Relief (2020) and Hurricane Sandy's Occupy Sandy (Homeland Security Studies and Analysis Institute 2013). As outlined in the Homeland Security Studies and Analysis Institute's 2013 case study on Superstorm Sandy, "a disaster 'can contribute to communication breakdowns, unexpected conditions, the inability to garner or verify timely information, and an overall difficulty in mobilizing sufficient personnel and material resources in the days leading up to and immediately following the event" (p. 11).

Mutual aid groups operating under these volatile conditions are thus often, but not always, different in essential ways from those groups that find themselves embedded within communities for extended periods of time. Groups delivering support in the wake of a devastating hurricane, for instance, tend to be composed of informal volunteers, are structured horizontally rather than hierarchically, and are able to meet the needs of community members in ways that establish and build trust. The unpredictable conditions under which post-disaster mutual aid groups work, in addition to the comprehensive, structural disruptions that accompany events such as Hurricanes Katrina and Sandy, offer these groups the opportunity to not only be innovative in their implementation of relief efforts, but to also redress systemic social, political, and economic inequities.

18.3 Mutual Aid Post-COVID-19

The World Health Organization (WHO) officially declared COVID-19 a pandemic on March 11, 2020, prompting border closures and quarantines across much of the world. As businesses closed and "non-essential" services ceased, new mutual aid groups began forming. They differed from previous post-disaster relief efforts in several important ways. The pervasiveness of the pandemic meant that groups were emerging across the United States (and world) simultaneously but alone. Lockdowns and less strict "shelter-in-place" measures meant they had to leverage digital tools in their delivery of resources, services, and support. Finally, the perceived indefiniteness of the pandemic made this disaster relief for an ongoing disaster.

As reported by Jia Tolentino in *The New Yorker*, groups forming in March, "had immediately begun thinking about long-term self-management, building volunteer infrastructures […] and thinking about what could work for months rather than for days" (2020). Whereas the response to a hurricane can last for weeks, months, or even years, the storm itself is a contained event. But, COVID-19 is no hurricane. It has not come and gone. Its duration is unknown, and that uncertainty means new mutual aid groups must evaluate and decide to what extent it is possible, and feasible, to persist.

The question of persistence is multifaceted, raising issues concerning social capital and the availability and accessibility of material resources. But, the question of whether and how these groups can continue to support people whose needs have been left unmet by the state and charitable organizations can only be answered if we actually consider what it means for these groups to persist. If, in their efforts to maintain operations, groups relinquish their anti-state, communitarian approach, then are we left with a fundamentally different practice? And, if this is the case, are we in a better place than before?

The new generation of mutual aid groups tends to be hyperlocal and specialized in terms of the services they deliver. A directory curated by the anarchist Cindy Milstein currently lists hundreds of groups across 45 American states, five Canadian provinces, Britain, France, Germany, and Mexico (Milstein 2020). Although global in terms of their distribution, they are hyperlocal in action. As Meredith Horowski, Senior Director for Code for America's Brigade Network and a volunteer herself notes:

> In D.C. it's by ward. We have six or seven different wards in D.C. and there is a different mutual aid network for each. And then even within that, you have these pod- and tenant structures arising. So, you're organizing by street, you're organizing sometimes by building. (2020)

These groups offer support and services in specific areas for specific communities. In New York City, for example, groups variously provide food and housing, pay utility bills and medical expenses, assist with childcare, and offer shelter from domestic violence (NYC United Against Coronavirus 2020).

In Aurora, Colorado, a group of librarians assembles "kits of essentials for the elderly and for children who wouldn't be getting their usual meals at school," while in Seattle, "a large collective […] set out explicitly to help 'Undocumented, LGBTQI, Black, Indigenous, People of Color, Elderly, and Disabled, folxs who are bearing the brunt of this social crisis'" (Tolentino 2020).

A unique feature of mutual aid groups is their informality, enabling them to respond more quickly than large non-profit organizations and state-led programs, both of which have policies and protocols to consider before actually reaching community members. "We were able to respond much quicker, because we didn't have all the rules and regulations and restrictions on our participation," says Stephany Hoffelt, co-founder of Iowa City Mutual Aid Collective (2020).

In August, much of Iowa was hit hard by a powerful derecho, leaving thousands of Iowans, "with no power and no food and nothing except for what we were getting to them," says Hoffelt. "And it was a really delayed response [for the bigger organizations]. And it was because they get hung up on their bureaucratic red tape" (2020).

In addition to the informal nature of post-pandemic mutual aid groups, these networks are almost entirely technology-driven. The next section will explore some of the digital tools that mutual aid groups have been using during the pandemic, as well as their functions. It will also flag important issues such as digital divides, privacy concerns, and the cost of these tools.

18.4 Technology

From the beginning of lockdowns in Hubei, China in January 2020, residents of Wuhan and surrounding cities turned to technology to coordinate local responses and offer support to neighbors. Tech ethnographer Tricia Wang, who was conducting field work in Wuhan at the start of the pandemic, attributes residents' psychological resilience during weeks of quarantine to marrying the concept of *xiao qu* (小区)—an officially designated grouping of homes that literally translates to "small district"—with WeChat groups. By Wang's estimate, Wuhan now has at least 7,106 *xiao qu* groups among its 11.08 million residents (2020b), and by lockdown's end had become the city's organizing principle:

> From day to day, you relied on your *xiao qu* to understand "Where do I get food? Where do I find a hospital if I'm sick? How do I buy vegetables?" Everything had to be organized within the *xiao qu*. Previously, they were neighbors who didn't really know each other. Soon, they were spinning off separate groups for childcare and exercise groups. That's when I realized: *This is coming to America.* (2020)

Even before Americans began to self-isolate in mid-March, what Wang calls "hyperlocal groups" turned to technology for coordination. Ranging in complexity from Post-Its and flyers (Simon 2020) to group texts, (Tolentino 2020), to social networks such as Facebook and Reddit (Wang 2020a) to business productivity workflow tools including Google Docs, Slack, and Airtable (Tiffany 2020), organizing was done—by necessity—at a distance and primarily online.

In interviews with mutual aid network founders, the initial choice of technology was typically ad hoc, beginning with freely available tools and evolving at the pace of members' available resources and technological sophistication. In New York City, for instance, Brooklyn's Bed-Stuy Strong began on the messaging platform Slack, which it used for internal coordination and dispatching tasks, such as buying groceries. Facebook posts, flyers, and word-of-mouth via calls and texts were employed for promotion, and a Google Voice phone number for incoming requests (Tolentino 2020). In Queens, Astoria Mutual Aid used Google Forms to solicit neighbors' requests before recruiting volunteer programmers to create a system combining Airtable's workflow tools with private Slack channels for dispatching requests, built on open-source code from GitHub (Tiffany 2020).

By contrast, the Iowa City Mutual Aid Collective launched with a Facebook group and a handful of volunteers. "Facebook was just a nightmare," says Hoffelt, "because then you had to link people to this, and link people to that." Keeping it for outreach, the group quickly pivoted to using Google docs internally and a simple phone number for fielding requests. “We’re just kind of winging it and using what we can,” she admits (Hoffelt 2020).

Necessity aside, how do these nascent digital-first networks differ from their predecessors, and what advantages do they derive from it? One clear advantage appears to be the speed and scale of initial recruitment, especially during the early days of self-quarantining, before prolonged isolation and precarity set in. In New York City, for example, a new group named Invisible Hands attracted more than 1,200 volunteers in its first four days in March; Bed-Stuy Strong similarly drew hundreds daily (Tolentino 2020). With a handful of exceptions—such as Occupy Sandy, which mobilized as many as 60,000 volunteers at its peak (Homeland Security Studies and Analysis Institute 2013)—their initial growth trajectories handily surpassed previous groups.

Persistent knowledge-sharing tools such as publicly-available Google Docs and Wikis, supplemented by intentional social media communities such as Reddit, have also helped make once-tacit knowledge explicit and aided in both the sharing of best practices and starting new groups. For instance, Tricia Wang (2020a) published her own guide to founding hyperlocal communities in March, then helped launch Last Mile #NYCPPE, a volunteer effort to source and distribute more than 60,000 respirator masks to 200 frontline healthcare workers at the height of New York’s infection rate (About last mile #NYCPPE 2020). The system her team built to analyze requests and match them with mask stockpiles has been shared and deployed in eleven cities since.

Again, the technical sophistication of Wang’s group and others is determined in large part by the skills, acumen, and social capital of group members. While this gulf in expertise can be mitigated externally through designing audience-appropriate interfaces—whether a phone number or AirTable spreadsheet—does it place limits on the size and scope of the group from a socio-economic standpoint? Or worse, promote divisions between a tech-savvy elite and rank-and-file volunteers?

The phrase “digital divide” historically refers to the chasm between those with and without Internet access (van Dijk 2006), which has created serious difficulties during the pandemic for patients in need of telehealth (Ramsetty and Adams 2020) and the estimated 15–16 million public school students across the United States without adequate equipment for distance learning (Common Sense 2020). “When I think of the digital divide, I think of people who don’t have hardware,” says Hofstra law professor Michael Haber, who also belongs to the mutual aid collective Cooperation Long Island. “But this is more an issue of people who can sort of use the Internet, but for them Slack is just foreign” (Haber 2020).

New group founders can be keenly aware of this divide and/or the perception issues of leading with new technology. (“Look, we’re new, we’re so shiny, we’re on Slack!” is precisely the message Bed-Stuy Strong founder Sarah Thankam Mathews says she hoped to avoid.) (Tolentino 2020).

Another issue is the cost of such tools. Airtable and Slack use a “freemium” model offering core functionality at no cost, but with hard caps on critical features

—such as the number of database records or messages available. While Slack offers qualifying nonprofits with free paid plans for three months and Airtable's similar vow is open-ended, veteran civic technologists warn organizers not to become too attached to their tools (Airtable 2020; Slack 2020). "Extending that pledge is a key question," says Code for America's Horowski, "because you don't want to build too much on top of them if you know that in a year, you're going to have to pay $100 per month for a small volunteer group that isn't funded" (2020).

On the other hand, free tools such as Google's carry their own risks. *Surveillance capitalism* (Zuboff 2019) has come to describe the search giant's widely-copied business models of extracting and monetizing users' information. These practices, coupled with these companies' cooperation and in some cases close alliances with law enforcement (Haskins 2019), raises serious concerns about members' privacy and security. The Electronic Frontier Foundation has published detailed guidelines on data collection and retention, starting with a minimum of both (Okuda et al. 2020).

But interviews suggest leading with digital tools can impede trust by the communities they're trying to help:

> Some of the people we worked with didn't want to put their name and address in a Google Document, but they felt comfortable calling and feeling us out first to see if they trusted us with their information—instead of filling out a Google form without knowing who's on the other end of it. (Hoffelt 2020)

To mitigate these risks, established civic tech nonprofits such as Code for America began working with mutual aid groups in "bringing technical fluency" and experience in designing inclusive online communities, according to Horowski (2020). But these groups also represent an inversion of the organization's typical NGO top-down approach, "where folks say, 'Here's what you need to do and here are the resources to do it,'" she explains. "I think we're seeing the reverse of that, where the challenge for us becomes: how do we understand what's happening on the ground and then filter that up and share it across networks and spaces?".

A post-pandemic incarnation of this demand-driven approach is U.S. Digital Response (USDR), an all-volunteer organization launched in April by former U.S. government deputy CTOs and tech industry veterans. One of its first projects was "Neighbor Express," an open source mutual aid platform hosted by city governments rather than local groups. A similar service named "Storefront" matches local food producers with residents in need (US Digital Response 2020). "Mutual aid networks resemble marketplaces in that you have the needs on hand and help on the other, and what you're doing is matching," says Raylene Yung, co-founder and CEO of USDR (2020).

The tension in her statement between technological approaches to scaling or replicating mutual aid and its politics is the focus for the remainder of this chapter.

18.5 Will Mutual Aid Stay Mutual?

The evolution and persistence of these groups was one of the biggest questions to emerge from interviews with mutual aid group organizers. How can these networks continue to leverage digital tools over the long-run to meet the needs of those most affected by the pandemic? What does persistence look like? Should the focus be on scaling up these smaller, community-led groups into larger organizations? Or should the emphasis be on replicability and promoting best practices between groups so that they might proliferate across communities and cities?

Identifying immediate needs and what's working on the ground allows groups to zero in on the specifics of their locality. It also offers an opportunity to compare efforts with other groups and identify similar trends that can inform best practices across networks.

It also might not be a question of whether these groups *can* scale up and/or replicate, but whether they *should*. The issue has everything to do with the intrinsic tension that exists between scaling up and mutual aid's political valence. "How do we do mutual aid and also keep it tied to the deep root causes?" Dean Spade asks (2020a, b). "Work that's very militant, that's about actually drastically redistributing wealth and resources. Like if it's just mutual aid to keep managing the social problems for the wealthy, then that's really limited" (Spade 2020a, b). One of mutual aid's core elements, according to Spade, is that it is "participatory, solving problems through collective action rather than waiting for saviors," (2020a, b, p. 16). In this respect, mutual aid groups are inherently anti-state, since the State is structured hierarchically, directing and redirecting resources in a top-down approach to causes it deems worthy.

New mutual aid groups in the pandemic do not operate with pre-existing agendas. They respond to the community's needs as they appear and mobilize people in real time as events unfold. These groups are not subsumed under the "non-profit industrial complex" of large, top-down NGOs—a confusing phenomenon for some, as Hoffelt describes:

> Because, a lot of them are liberals, you know, [...] And, they see the term mutual aid and they aren't quite sure what's history or anything like that. And so they're all very, "Oh, that sounds good. We're going to do a mutual aid group." And so then, you know, they would ask me things like, well, how do you decide who qualifies? And I'd be like, "They ask me for food." (Hoffelt 2020).

To what extent these new mutual aid groups evolve during and after the pandemic—and what that evolution will look like—will depend on a number of unpredictable variables. What should remain steady in this evolution, however, is the core mandate of these groups to care for, support, and build community.

18.6 Conclusion

What happens after coronavirus? Unlike Hurricanes Katrina or Sandy, there will likely be no “after.” Already, groups like Iowa City Mutual Aid are pivoting from one disaster to the next—from the pandemic to August’s destructive derecho—and on to social justice, unemployment, and eviction crises. For this reason, and the reasons enumerated above, mutual aid groups are poised to play a more prominent role in maintaining community resilience than at any point in their history. But what will their role be?

In research and interviews with members, their short-term trajectory is continuing to add necessary functions. For example, several subjects suggested mutual home schooling as a potential next step given school closings or potential risk of infection. A bigger question is the tension between online and offline organizing, and whether technology-enabled lower barriers to entry will prove to be a radicalizing force or foreground material relief at the expense of politics. Unsurprisingly, organizers and civic technologists have differing foci. “It’s a great on-ramp, and it needs to be an on-ramp that’s explicitly politicizing, but one that’s also open enough” to new participants, argues Spade.

Code for America’s Horowski prefers to focus on the current inversion of online-to-offline activism, as organizers who previously struggled to convert petition-signers and ActBlue donors into committed participants now strive to harness the energy and engagement of people willing to risk injury, arrest, and the pandemic on behalf of Black Lives Matter, then channel it into a Slack channel or Airtable spreadsheet. “Pulling people offline-to-online is also important in the interplay and architecture of mutual aid spaces and community networks,” she says.

Both agree, however, that sustained success won’t come from “scaling” local efforts into models that can be imposed elsewhere:

> Mutual aid is not about standardizing. It’s about replicating—taking the best from you and doing it the way that works for our community. It's based on the idea that local knowledges are actually essential. That’s key to me, and it’s a very anarchist principle, in my view. (Spade 2020a, b)

An unresolved question is where these bottom-up efforts will ultimately intersect with government aid, regulation, and enforcement, and official narratives of the pandemic. As the Superstorm Research Lab documented in the aftermath of Sandy, actors and institutions initially absent—including the Red Cross and FEMA—later worked both closely- and at cross-purposes with local activists (Liboiron and Wachsmuth 2013). It remains to be seen how this phenomenon may play out simultaneously among thousands of groups capable of learning from each other.

Another possible outcome is the continued evolution of mutual aid groups into organizations of sufficient complexity to challenge or even capture the state at the local level. “New municipalism” groups such as Barcelona’s Barcelona en Comú (Barcelona en Comú et al. 2019) and Jackson, Mississippi’s Cooperation Jackson (Nangwaya and Akuno 2017) not only aim to transform the relationship between city government and the governed, but have also delivered mutual aid throughout the pandemic as well. "Don't just think of it as food delivery—and most groups don't," says Hofstra's Haber (2020). "It's about how we can make this a long-term organizing project for making decisions about what we want our communities to be like."

References

About last mile #NYCPPE (2020) Last Mile #NYCPPE. https://www.nycppe.org/about-us

Airtable (2020) Airtable's support for COVID-19 response efforts. For the Record. https://blog.airtable.com/airtables-support-for-covid-19-response-efforts/

Barcelona en Comú., Bookchin D, Colau A (2019) Fearless cities: a guide to the global municipalist movement. Verso.

Common Ground Relief (2020) About us. https://www.commongroundrelief.org/about-us/

Common Sense (2020) K-12 student digital divide much larger than previously estimated and affects teachers, too, new analysis shows. Common Sense Media, 29 June 2020. https://www.commonsensemedia.org/about-us/news/press-releases/k-12-student-digital-divide-much-larger-than-previously-estimated-and

Haber M (2020) Personal communication

Haskins C (2019) 'FUCK CRIME:' inside ring's quest to become law enforcement's best friend, 4 December 2019. https://www.vice.com/en_ca/article/bjw9e8/inside-rings-quest-to-become-law-enforcements-best-friend

Hoffelt S (2020) Personal communication

Homeland Security Studies and Analysis Institute (2013) The resilient social network. https://assets.documentcloud.org/documents/1357203/the-resilient-social-network.pdf

Horowski M (2020) Personal communication

Kropotkin P (1902) Mutual aid: a factor of evolution. The Anarchist Library. https://theanarchistlibrary.org/library/petr-kropotkin-mutual-aid-a-factor-of-evolution

Kujala A, Danielsbacka M (2018) Reciprocity in human societies: from ancient times to the modern welfare state. Palgrave Macmillan

Liboiron M, Wachsmuth D (2013) The fantasy of disaster response: governance and social action during hurricane sandy. Social Text Online. https://socialtextjournal.org/periscope_article/the-fantasy-of-disaster-response-governance-and-social-action-during-hurricane-sandy/

Milstein C (2020) Collective care is our best weapon against COVID-19. Mutual Aid Disaster Relief. https://mutualaiddisasterrelief.org/collective-care/

Nangwaya A, Akuno K (2017) Jackson rising: the struggle for economic democracy and Black self-determination in Jackson, Mississippi. Daraja Press. https://jacksonrising.pressbooks.com/

NYC United Against Coronavirus (2020) Resources and information. https://docs.google.com/document/d/18WYGoVlJuXYc3QFN1RABnARZlwDG3aLQsnNokl1KhZQ/edit

Okuda S, Greenberg W, Elam B, Tsukayama H (2020) Keeping each other safe when virtually organizing mutual aid. Electronic Frontier Foundation, 30 March 2020. https://www.eff.org/deeplinks/2020/03/keeping-each-other-safe-when-virtually-organizing-mutual-aid

Ramsetty A, Adams C (2020) Impact of the digital divide in the age of COVID-19. J Am Med Inform Assoc 27(7):1147–1148. https://doi.org/10.1093/jamia/ocaa078

Simon S (2020) Volunteer group helps at-risk New Yorkers as coronavirus spreads. NPR, 28 March 2020. https://www.npr.org/2020/03/28/823071202/volunteer-group-helps-at-risk-new-yorkers-as-coronavirus-spreads

Slack (2020) We're here to help your team's Covid-19 efforts. https://slack.com/intl/en-ca/resources/using-slack/covid-help

Slavin K (2020) Personal Communication

Spade D (2020a) Mutual aid: Building solidarity during this crisis (and the next). Verso

Spade D (2020b) Personal communication
Tiffany K (2020). Pandemic organizers are co-opting productivity software. The Atlantic, 28 May 2020. https://www.theatlantic.com/technology/archive/2020/05/coronavirus-mutual-aid-groups-slack-airtable-google/612190/
Tolentino J (2020) What mutual aid can do during a pandemic. The New Yorker, 11 May 2020. https://www.newyorker.com/magazine/2020/05/18/what-mutual-aid-can-do-during-a-pandemic
US Digital Response (2020) About. https://www.usdigitalresponse.org/about/
van Dijk J (2006) Digital divide research, achievements and shortcomings. ScienceDirect 34(4–5):221–235. https://doi.org/10.1016/j.poetic.2006.05.004
Wang T (2020a) How to create your own #HyperlocalGroup, 21 March 2020. https://docs.google.com/document/d/1Ys6crbTIDSN0QxPe-SQOiO0bdZlqHmqAG79RKtLMDDE/edit
Wang T (2020b) Opinion: you can learn something from the people of Wuhan. BuzzFeed News, 24 March 2020. https://www.buzzfeednews.com/article/triciawang/a-lesson-from-the-people-of-wuhan-community-hyper-local
Zuboff S (2019) The age of surveillance capitalism. Public Affairs

Chapter 19
Understanding How Community Resilience Can Inform Community Development in the Era of COVID

Ann Carpenter, Dontá Council, and Jasmine Burnett

Abstract The role of community development in the wake of the COVID-19 outbreak is multifold, with an opportunity to promote more robust community resilience. Given the increasing salience of shocks and stressors and their short- and long-term impacts on low- to moderate-income communities and communities of color, community development professionals can also contribute to understanding and facilitating an inclusive recovery. We theorize community resilience as a process rather an outcome and apply a resilience lens to previous recovery policy efforts and their impacts. Finally, this chapter concludes with a broad framework and applications that community development and emergency management practitioners and researchers may consider to understand and meet the needs of the most vulnerable communities impacted by COVID-19.

Keywords Community development · Community resilience · COVID-19 · Inclusive recovery · Inequality

19.1 Introduction

Community development has typically been focused on increasing the prosperity and quality of life of lower-income individuals, families, and neighborhoods. Through this work, the ecosystem of community development organizations serves historically disadvantaged populations who are most socially vulnerable to external stresses like the current COVID-19 pandemic.

However, this network of organizations is rarely engaged in pre-disaster or resilience planning. Following a natural disaster, volunteer organizations active in a

The comments in this chapter are those of the authors alone and do not necessarily reflect the views of the Federal Reserve Bank of Atlanta or the Federal Reserve System.

A. Carpenter (✉) · D. Council · J. Burnett
Federal Reserve Bank of Atlanta, Atlanta, Georgia
e-mail: ann.carpenter@atl.frb.org

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_19

disaster (VOADs) and long-term recovery organizations (LTROs) that include community development practitioners may be activated and incorporated into a formal recovery process, but this infrastructure tends to dissipate once the immediate crisis period is over.

Is this a missed opportunity? Could community development widen its focus to explicitly include activities that promote resilience? In addition to common community development goals such as increasing community capacity, abating joblessness, developing real estate, or supporting small businesses, how can community development focus on insulating socially vulnerable populations, such as communities of color, low-income, and low-wealth households, from future shocks? Can participation from the community development sector also ensure that equitable outcomes are achieved in recovery and that previous inequities are not further entrenched? We examine the impacts of COVID-19 on these communities and propose a role for community development that supports an inclusive recovery and the potential for more robust and equitable community resilience. Additionally, we conceptualize community resilience as a process and outcome that can inform and enhance community development.

19.2 Defining Community Resilience and Community Development

Given the intensity of the pandemic's initial impact and its unknown duration and lasting effects, COVID-19 presents a significant challenge to community resilience. Engineering and ecological resilience are often defined as the ability of a system to absorb a disturbance and persist, or maintain its previous properties (Holling 1973). Others define resilience as "the capacity of a system to absorb disturbances and reorganize while undergoing change" (Walker et al. 2004), highlighting the potential for change following a disruption. For communities, resilience to shocks and stresses suggests that residents are able to remain in a community with the resources available to maintain their previous quality of life. Disturbances may come in various forms: recurrent natural disasters such as seasonal flooding or hurricanes; less predictable events such as a major tornado; and once in a generation, large scale catastrophes like the current COVID-19 pandemic. Climate change has increased the scale and frequency of even the most common disasters along with associated costs to human life and property (Coronese et al. 2019). Physical exposure to disasters and greater vulnerability, in part due to social disadvantage, have also driven greater losses. As a result, many communities remain in long-term recovery mode for extended periods. The need for greater community resilience to shorten this recovery period is apparent.

While many scholars and practitioners have focused on communities returning to their pre-shock or pre-stressor conditions as a benchmark to assess community resilience, we recognize that these pre-event conditions often reflect deep inequities that are not necessarily the current resident's desired outcomes. Therefore, we extend the concept of community resilience to incorporate principles of equity and inclusion. In doing so, we explicitly emphasize the impacts of shocks and stresses on historically marginalized communities and the potential to exploit and explore the role of community development in promoting an equitable recovery and greater community resilience. If communities are to be resilient, they must engage in the due diligence of interrogating, acknowledging, and documenting the social inequalities that contribute to pre-event conditions and may slow recovery for vulnerable populations.

Community development is a set of activities and processes that foster the social, economic, and human capital of a community and "the capacity of a social system to come together to work toward a common goal" (Berkes and Ross 2013). The process of community development allows community members to identify and redefine local capacities and assets to improve community assets and functions in line with community values (Eversole 2015). People-based approaches focus on individuals and households in need, while place-based approaches concentrate resources on a specific geography in need. Community development also confers intangible benefits such as social cohesion, creating a sense of place, and empowering community members. Increasingly, community development leaders are acknowledging the urgency of including racial equity and inclusion in their work (Andrews 2019).

Community resilience and community development share many guiding principles and objectives, though these fields are not often in dialogue. This is because conceptually, scholars and practitioners have struggled to understand the context of resilience in the face of adversity at the community level (Patel et al. 2017). Fundamentally, community resilience is a process and outcome that can inform and enhance community development. Together, these processes may contribute to more desirable, equitable outcomes post-recovery when shocks are experienced and can position communities to mitigate the impacts of future shocks. The COVID-19 pandemic can serve as an impetus for greater collaboration and communication among these fields due to the disproportionate impact the pandemic is having on disadvantaged communities, particularly communities of color, and the essential role of community development in responding to the needs of lower-income populations.

19.3 The Impacts of COVID-19 on Communities

The COVID-19 pandemic presents an unusual challenge in its scale and unprecedented nature. Within months, COVID-19 claimed more than 200,000 lives, halted business activity, suspended day-to-day services, and left millions struggling to survive. Not surprisingly, it also impacted the network of public, private, and nonprofit organizations that are actively engaged in community development work. Within the community development field, a national survey found that 69 percent of organizations reported significant disruption in April 2020, with the most frequently cited impacts being staffing constraints, increased demand for services, and budget constraints (Davis et al. 2020). The need to operate virtually has also strained many organizations.

The effect of the novel virus has been particularly pronounced in the populations of concern to community development professionals, including communities of color, those of high poverty, and those in rural areas. According to the New York Times, through August 15, 2020, the infection rate in majority-minority metropolitan counties was 206 per 10,000 persons, compared to 169 per 10,000 across all counties (The New York Times 2020). Infection rates were even higher for counties experiencing persistent poverty, or those with greater than 20 percent poverty over 30 years, in which the infection rate was 246 per 10,000. Among non-metro counties, the infection rate was 122 per 10,000; however, minority and income disparities were even wider in non-metro counties, with majority-minority and persistent poverty counties experiencing infection rates at 259 and 221 per 10,000, respectively (The New York Times 2020).

Given these figures, community development professionals involved in workforce development, small business support, and affordable housing have been concerned by the fallout and effectiveness of the response. From March 21 through August 8, more than 56 million people have applied for unemployment benefits, one clear indicator of the economic ramifications of the COVID-19 outbreak and subsequent business closures.[1] The national unemployment rate peaked at 14.7 percent in April, and declined to 7.9 percent in September.[2] While future impacts of COVID-19 on employment are uncertain, health professionals predict that there is a possibility of another large spike of positive cases (Maragakis 2020), suggesting a long road to full economic recovery. Unemployment figures are higher for Black and Latinx families during the crisis. Based on an Urban Institute analysis of U.S. Census Bureau Household Pulse Survey data, in early June, 53 percent of Black households and 62 percent of Latinx households reported that at least one person in their household had lost employment income as of mid-March, as compared to only 48 percent of white households (Brown 2020).

Small businesses, particularly minority-owned businesses, have been disproportionately impacted by the pandemic. From February to April, the number of all active business owners in the U.S. decreased by 22 percent, while Black-owned businesses decreased by 41 percent (Fairlie 2020). Nonprofit organizations, including many community development entities, have also struggled. A recent report by Johns Hopkins noted significant job cuts to the nonprofit sector (1.6 million total jobs) between April and May 2020, particularly in fields such as educational services and social assistance, which are central to community development (Salamon and Newhouse 2020).

[1]U.S. Department of Labor Employment & Training Administration r539cy data.

[2]U.S. Bureau of Labor Statistics Table A-2 and A-3, Household data.

As the effects of the pandemic worsen, housing insecurity is a growing concern for many lower-income families and community development practitioners. With eviction and foreclosure moratoria expirations looming, Black and Latinx families, who are more likely to be renters, will be disproportionately impacted by the resulting housing displacement, based on higher levels of deferred rent and mortgage payments during the pandemic (Ricketts 2020). Data from the Atlanta Eviction Tracker reveals that court filings for evictions are returning to similar rates as before the onset of COVID-19. In January 2020 there were a reported 13,961 evictions filed across the Georgia counties of Clayton, Cobb, DeKalb, Fulton, and Gwinnett. By March 2020, the total across the five counties dropped to 8,810, and by April 2020, the total had dropped to 1,122. These temporary decreases in evictions allowed families to stay in their homes as they weathered the effects of the pandemic. Without an extension of eviction and foreclosure moratoria, households experiencing financial insecurity—consisting disproportionately of racial and ethnic minorities who have experienced greater levels of unemployment—may find themselves without stable and affordable housing.

19.4 Inclusive Recovery as a Path to More Robust Resilience

Inclusive recovery has been aptly defined as occurring "when a place overcomes economic distress in a way that provides the opportunity for all residents—especially historically excluded populations—to benefit from and contribute to economic prosperity" (Poethig et al. 2018). Policies and investments that achieve this goal integrate the knowledge and values of the intended beneficiaries, ensure participation and/or decision-making rights at the financial level, and flexibly meet the specific needs of recipients. We turn to lessons from the Great Recession to understand how previous recovery policy impacts community resilience and to reflect on the need for an inclusive recovery strategy that incorporates the community development field.

The previous recession and recovery had a significant impact on underserved communities, which were slower to recover and generally less resilient (Hyra and Rugh 2016). Though racial disparities in housing, wealth and small businesses existed before the Great Recession, these gaps widened during the 2007–2009 financial crisis, limiting the ability of communities of color to withstand another shock. Notably, the racial wealth gap widened in the immediate aftermath of the recession, though the gap differed by income strata.income strata. The wealth gap remains substantial: in 2016, the median white household held ten times the amount of wealth as the median Black household (Kochhar and Cilluffo 2017). Given the importance of financial security in fostering resilience, these existing racial wealth disparities are troubling.

The housing crisis also had disparate impacts by race, with majority-Black neighborhoods experiencing larger declines in home prices and slower recovery (Raymond et al. 2016). Many well-intentioned programs attempted to stabilize homeowners, but failed to reach minority families. For instance, to stabilize the housing market, the Home Affordable Modification Program (HAMP) sought to reduce foreclosures by reducing participants' monthly mortgage payments. A survey conducted by the National Community Reinvestment Coalition found that among eligible borrowers, white homeowners were nearly 50 percent more likely to obtain a loan modification than Black program applicants. Moreover, relative to white and Hispanic program participants, Black homeowners saw a smaller decline in their interest rates post-modification. The average decline in interest rates for Black survey respondents was 2.84 points—0.48 points lower than the average for white respondents and 0.51 points lower than the average for Latinx respondents (National Community Reinvestment Coalition 2010).

Although we are more than six months into this pandemic, much is still unknown about how it will unfold and what forms aid will take. Early income replacement programs and eviction and foreclosure moratoria helped to keep many lower-income households afloat, but without further intervention a cliff is imminent. Longer term recovery policy is uncertain, yet the outcomes of the Great Recession highlight how recovery and resilience policies without an explicit equity lens may widen existing disparities. To prevent the further widening of disparities, it is important to address the particular legacy of disadvantage experienced by racial and ethnic minorities across housing, income, wealth, and entrepreneurship. There is an opportunity for community development practitioners and scholars to play a role in promoting inclusive recovery and resilience at this moment.

However, community development practitioners find themselves with limited resources and an uncertainty about the resources that they and their constituents will have access to. The COVID-19 recession has had significant, and unexpected, impacts on both the supply and demand drivers of the economy and has the potential to further weigh down lower-income communities through an emerging "k-shaped" (K) recovery, in which certain households, regions, and sectors seem to be prospering at a greater rate while others struggle. To successfully address the aforementioned economic and health-related racial disparities, inclusive economic recovery policies and public investment in the resilience of communities are required. This includes providing assistance and credit to low-to-moderate income households, small businesses, and others on the downward trajectory of the "K". Without this targeted approach, the inequities that widened after the last recession will grow even larger during and in the aftermath of this pandemic.

19.5 A Community Development Framework

Community development offers a platform for resilience and promising solutions to issues of equity in the context of shocks and stresses such as the COVID-19 pandemic. Many community development practices are intentionally designed to operate within the specific contexts of the communities they are applied to. As such, they can be successful in identifying and addressing disparities. We offer basic theory and approaches that help to situate resilience and equity in community development.

Fundamentally, community development seeks to improve a community in tangible and intangible ways. The notion of *community capitals* was introduced to apply a systems perspective to relationships between specific elements that the field aims to leverage and enrich (Flora and Flora 2008). The seven types of community capitals recognized as important considerations of community development are natural, cultural, human, social, political, financial, and built capital. All are important for increasing resilience, directly and indirectly; however, among the community capitals, social capital has been singled out as a particularly important driver of community resilience. Social capital is a byproduct of one's social networks of support, often described in terms of benefits such as access to information and resources. Bridging and linking social capital (between social groups) is necessary to support longer term recovery at the community level, while bonding social capital (within social groups) is necessary for household-level survival (Hawkins and Maurer 2010).

There are three commonly applied community development approaches that work to enhance these capitals. These include self-help, technical assistance, and social conflict (Green 2008).

Self-help is community driven, characterized by actions that build the capacity of a community with a focus on existing assets. For example, Council, Covi, Yusuf, Behr, and Brown (2018) found that many low- and moderate-income residents in Portsmouth, Virginia (a coastal region vulnerable to the recurrent shocks of flooding) engaged in self-organizing, and were thus likely to engage with governments. As a result, the study found that neighborhoods and communities developed networks to navigate severe weather storms. Self-help can be thought of as "grassroots" or "bootstrap" approach and has the added benefit of strengthening community networks, a key element of resilience. Practitioners of this model act as facilitators, assuming that their primary goal is to help people learn how to help themselves.

Technical assistance is straightforward to operationalize, but generally relies on outside experts, who may lack on-the-ground knowledge. Practitioners of the technical assistance model assume that information access and information deficiency are the biggest hurdles that communities face (Green and Haines 2015). From a resilience perspective, this approach may include developing culturally-appropriate educational materials and planning scenarios that are consistent with "community perceptions, beliefs, attitudes, and needs" (Paton 2000).

Social conflict is the action or process in which community representatives seek to enact positive change through community mobilization. This approach empowers community members, develops agency, and strengthens networks, thus increasing resilience. Disasters are a breeding ground for social conflict, which has been argued to provide a catalyst for resilience and adaptive change during the post-disaster recovery phase (Stephenson 2011). Community-based organizations and community leaders, including those from the community development field, can play a central role in this activity and in forming bridges between residents and large institutions.

19.6 Applying the Framework: How to Braid Community Development and Community Resilience in Practice

A strategy for incorporating community resilience in community development begins with embracing resilience principles, a shared understanding of systemic barriers and goals, and process improvements. We offer several examples of how community development can be instrumental in building community resilience in practice.

An understanding of the universe of actors that engage in community development is important, as they may serve as natural allies for resilience work. Organizations involved in community development are diverse, including community-based organizations; community development corporations; financial institutions; public agencies; universities, hospitals, and other anchor institutions; faith-based organizations; and many more. Along with informal networks that provide bonding social capital, these and other formal organizations are associated with greater levels of trust and social capital (Putnam 2000) and, importantly, resilience (Aldrich 2012). Notably, Jacobs (2019) emphasized the need to incorporate local knowledge, often held by these organizations, into disaster planning efforts. In particular, community-based and faith-based organizations are often vital, trusted sources of information and resources post-disaster. Furthermore, ties between organizations both within and outside of a community support increased communication and collaboration and thus, capacity for recovery and resilience (Berke et al. 1993).

As noted previously, community development organizations typically do not identify resilience as a goal. Accordingly, there is an opportunity to build awareness and buy-in of how their work intersects with resilience and to engage these organizations more intentionally in emergency management activities, particularly in the pre-disaster and long-term recovery spaces. These organizations may lack knowledge or capacity to independently develop resilience strategies; however, outreach to this community, at minimum, could be beneficial in better understanding community perspectives and needs, promoting resilience and mitigation strategies within broader populations, and developing robust networks of resilience champions.

Community development tools could also be leveraged to increase community resilience. These tools include previously mentioned technical assistance and capacity building or self-help activities, as well as financial instruments. Financing community development can often include public, private, and philanthropic resources, such as bonds, grants, and equity investments. Many of these financial resources provide means to foster resilience. Community development financial institutions (CDFIs), for example, are lenders and loan funds with an express purpose of providing capital to lower-income, lower-wealth, and other underserved households and communities.

There are various examples of CDFIs supporting climate resilience and disaster recovery, roles that fit their mission-driven orientation and play to their strengths as patient and flexible investors. A case study of one CDFI found that its loan fund outperformed similar real estate lending by commercial banks during the Great Recession (Latimer-Nelligan and Seidman 2015). A second relevant community development financial tool is the social impact bond, which can be used to attract private capital to promote a communal benefit, such as mitigating the impacts of devastating shocks. A social impact bond raises capital for a program with a defined social benefit and rewards investors when success across predetermined metrics is met. Social impact bonds have been used in a variety of situations, are a promising strategy for promoting resilience, and, even prior to the current public health crisis, were considered a viable option for global pandemic preparedness (Snair and Snair 2016).

Asset-based strategies, wherein community development focuses more holistically on the root causes of existing disparities and addresses the needs of residents, can also promote resilience. Local wealth building is an example of an asset-based strategy that promotes household- and community-level resilience through greater financial stability. Local wealth building seeks to close the wealth gap by race and class in the U.S. by engaging local stakeholders and directing capital to historically disadvantaged residents and businesses. This may include activities that build on and produce local power through a plural or collective ownership model, like a worker-owned cooperative or a community land trust for affordable housing. The local wealth building framework can provide a robust set of outcomes such as growth of jobs with meaningful work, equity, inclusion, environmental sustainability and economic stability (McInroy 2018). Given the relationship between financial stability and household or community resilience, this approach is an important opportunity for community development to support greater resilience.

Cross-sector collaborations are characteristic of community development and provide opportunities for supporting resilience goals. The current health crisis underscores the importance of the intersection between health and community development. In particular, two relatively new approaches to health benefit greatly from community development and have clear ties to resilience. First, the whole community approach to public health, which mirrors a similar concept in emergency management, draws on the experiences of all stakeholders in a community in public health planning and implementation. The whole community approach focuses on community needs and building trusted partnerships to address them. An example of its success is in reducing health disparities among the Cambodian population of Lowell, Massachusetts (Grigg-Saito et al. 2010). Second, healthcare providers and insurers are increasingly interested in the social determinants of health, such as access to safe and affordable housing, understanding that where you live is as fundamental to health outcomes as are clinical interventions (Fazili 2017). Thus, community development and public health practitioners should harness this momentum and continue to develop cross-disciplinary strategies to address the current crisis and health equity and resilience in general. Health disparity metrics should be tracked and incorporated in an evidence-based approach to recovery and to strengthen resilience in the future. In order to foster resilience, communities that experienced historic and present disinvestment should not be left behind, particularly where COVID-19 infection rates, comorbidities, and deaths are elevated.

19.7 Conclusion and Recommendations

The call for community resilience to be incorporated into community development approaches (and vice versa) is increasing in urgency. Scholars have noted that capacity building, empowerment, and strengthening of social networks that are advanced by community development naturally promote resilience (Cavaye and Ross 2019). One reason cited for the divide between the fields is the disconnect between the small, sometimes neighborhood-level scale at which community development takes place and the multilevel or regional approach of resilience (Cavaye and Ross 2019). This is particularly challenging in relation to COVID-19, as there is significant regional variation in the impacts of the disease, the local non-pharmaceutical interventions, and the fiscal stimulus, and many conduits for assistance are not designed to reach individuals or communities. Models that involve grassroots leadership may be considered in identifying community-based leaders to engage with wider planning and resource networks.

Community development practitioners' and scholars' role is to assist in creating capacity and shifting power dynamics and relationships, ideally with equity and inclusion in mind. This means that active representation and active participation are required from community members in decision-making processes. Through this work, community assets and capitals are enhanced and developed to appropriately facilitate desired change, including, potentially, greater community resilience.

We believe several practical strategies for building a bridge between the domains of community development and community resilience are ripe for implementation. These include:

- Engagement of the community development profession and inclusion of community perspectives and needs in emergency management, including resilience and long-term recovery planning
- Hazard and resilience education for residents and organizations in community development work
- Intentional development of networks between community development and emergency management professionals, explicitly emphasizing multi-scale, mutual resilience efforts and providing a space for leadership development and peer-exchanges

- Targeted community development investments and financial tools that address resilience for socially disadvantaged populations, particularly communities of color
- Leveraging the connection between community development, healthcare, and resilience, given the current public health crisis
- Using data disaggregated by race and other socioeconomic variables to track the recovery and ensure communities of color and other vulnerable populations do not fall further behind

The need is clear for a greater dialogue between entities that engage in the work of community development and emergency management planning focused on resilience. The inclusion of community development in this work presents the opportunity to explicitly acknowledge historical conditions as well as increase engagement with communities to improve community trust, a crucial element in community resilience. Cross-sectoral collaborations with community-based organizations, CDFIs, and other community organizations may deepen the ability to promote resilience by marshalling resources to more adequately address the needs of individual communities.

COVID-19 has highlighted the need for greater understanding of community needs and allocation of assistance to the most vulnerable. Community development organizations can offer expertise in these areas. The pandemic creates an opportunity for community development practitioners and scholars to better understand and engage in inclusive recovery and resilience building efforts to reduce disparities now and in the future. Without intervention, COVID-19 will deepen existing economic and health disparities for low-to-moderate income households and communities of color. Communities' abilities to adjust, adapt, and absorb shocks will also be compromised.

References

Aldrich DP (2012) Building resilience: social capital in post-disaster recovery. University of Chicago Press, Chicago, IL

Andrews NO (2019) Race, gender, and equity in community development: ten findings, six ways forward. Retrieved from Brookings Institution https://www.urban.org/sites/default/files/publication/101142/race_gender_and_equity_in_community_development_ten_findings_six_ways_forward_1.pdf

Berke PR, Kartez JD, Wenger D (1993) Recovery after disaster: achieving sustainable development. Mitigation and Equity. Disasters 17(2):93–109

Berkes F, Ross H (2013) Community resilience: toward an integrated approach. Soc Nat Resour 26(1):5–20. https://doi.org/10.1080/08941920.2012.736605

Brown S (2020) The COVID-19 crisis continues to have uneven economic impact by race and ethnicity. Retrieved from The Urban Institute https://www.urban.org/urban-wire/covid-19-crisis-continues-have-uneven-economic-impact-race-and-ethnicity

Cavaye J, Ross H (2019) Community resilience and community development: What mutual opportunities arise from interactions between the two concepts? Community Dev 50(2):181–200. https://doi.org/10.1080/15575330.2019.1572634

Coronese M, Lamperti F, Keller K, Chiaromonte F, Roventini A (2019) Evidence for sharp increase in the economic damages of extreme natural disasters. Proc Natl Acad Sci 116 (43):21450–21455. https://doi.org/10.1073/pnas.1907826116

Council D, Covi M, Yusuf W, Behr J, Brown M (2018) The 'new normal' of flooding in Portsmouth, Virginia: Perspectives, experiences, and adaptive responses of residents and business owners in low to moderate-income communities. Retrieved from Old Dominion University Resilience Collaborative https://digitalcommons.odu.edu/odurc-presentations/15/

Davis DP, Kaufmann D, Leone de Nie K (2020) Perspectives from main street: the impact of COVID-19 on communities and the entities serving them. Retrieved from Federal Reserve System https://www.frbatlanta.org/-/media/documents/community-development/publications/federal-reserve-system-resources/05/04/perspectives-from-main-street-the-impact-of-covid-19-on-communities.pdf

Eversole R (2015) Knowledge partnering for community development. Routledge, Abingdon

Fairlie R (2020) The impact of COVID-19 on small business owners: evidence of early-stage losses from the April 2020 current population survey. Retrieved from National Bureau of Economic Research https://www.nber.org/papers/w27309

Fazili S (2017) Can community development improve health? Emerging opportunities for collaboration between the health and community development sectors. Retrieved from Atlanta, GA

Flora C, Flora J (2008) Rural communities, legacy + change, 3rd edn. Westview Press, Boulder, CO

Green GP, Haines A (2015) Asset Building & Community Development: Sage Publications

Green JJ (2008) Community development as social movement: a contribution to models of practice. Commun Dev 39(1):50–62. https://doi.org/10.1080/15575330809489741

Grigg-Saito D, Toof R, Silka L, Liang S, Sou L, Najarian L … Och S (2010) Long-term development of a "whole community" best practice model to address health disparities in the cambodian refugee and immigrant community of Lowell, Massachusetts. Am J Public Health 100(11), 2026–2029

Hawkins RL, Maurer K (2010) Bonding, bridging and linking: how social capital operated in new Orleans following Hurricane Katrina. Br J Soc Work 40:1777–1793

Holling CS (1973) Resilience and stability of ecological systems. Annu Rev Ecol Syst 4:1–23

Hyra D, Rugh JS (2016) The US great recession: exploring its association with black neighborhood rise, decline and recovery 37*, 5*(700–726)

Jacobs F (2019) Black feminism and radical planning: new directions for disaster planning research. Plan Theory 18(1):24–39

Kochhar R, Cilluffo A (2017) How wealth inequality has changed in the U.S. since the Great Recession, by race, ethnicity and income. Retrieved from Pew Research Center https://www.pewresearch.org/fact-tank/2017/11/01/how-wealth-inequality-has-changed-in-the-u-s-since-the-great-recession-by-race-ethnicity-and-income/

Latimer-Nelligan K, Seidman E (2015) Weathering the Great Recession: A CDFI Case Study in Patient Capital. Retrieved from Federal Reserve Bank of San Francisco https://www.liifund.org/wp-content/uploads/2015/09/CDFI-Patient-Capital-Working-Paper.pdf

Maragakis LL (2020) First and Second Waves of Coronavirus. Retrieved from Johns Hopkins University https://www.hopkinsmedicine.org/health/conditions-and-diseases/coronavirus/first-and-second-waves-of-coronavirus

McInroy N (2018) Wealth for all: building new local economies. Local Econ 33(6):678–687

National Community Reinvestment Coalition (2010) HAMP mortgage modification survey

Patel SS, Rogers MB, Amlôt R, Rubin GJ (2017) What do we mean by 'community resilience'? A systematic literature review of how it is defined in the literature. PLOS Currents Disasters. doi: https://doi.org/10.1371/currents.dis.db775aff25efc5ac4f0660ad9c9f7db2

Paton D (2000) Emergency planning: integrating community development, community resilience, and hazard mitigation. J Am Soc Prof Emerg Plan 7:109–118

Poethig E, Greene S, Stacy C, Srini T, Meixell B (2018) Inclusive recovery in US Cities. Retrieved from Urban Institute https://www.urban.org/sites/default/files/publication/97981/inclusive_recovery_in_us_cities.pdf

Putnam RD (2000) Bowling alone: the collapse and revival of american community. Simon and Schuster, New York City, NY

Raymond E, Wang K, Immergluck D (2016) Race and uneven recovery: neighborhood home value trajectories in Atlanta before and after the housing crisis. Hous Stud 31(1):324–339

Ricketts L (2020) Housing distress in the time of COVID-19. On the Economy Blog. Retrieved from https://www.stlouisfed.org/on-the-economy/2020/august/housing-distress-time-covid19

Salamon LM, Newhouse CL (2020) The 2020 Nonprofit Employment Report. Retrieved from JohnS Hopkins Center for Civil Society Studies https://ccss.jhu.edu/wp-content/uploads/downloads/2020/06/2020-Nonprofit-Employment-Report_FINAL_6.2020.pdf

Snair J, Snair MR (2016) Social impact bonds & sustainable disaster risk reduction. Domestic Preparedness. Retrieved from https://www.domesticpreparedness.com/resilience/social-impact-bonds-sustainable-disaster-risk-reduction/

Stephenson MO Jr (2011) Considering the relationships among social conflict, social imaginaries, resilience, and community-based organization leadership. Ecol Soc 16(1)

The New York Times (2020) Covid in the US: latest map and case count. Retrieved from https://www.nytimes.com/interactive/2020/us/coronavirus-us-cases.html

Walker B, Holling CS, Carpenter SR, Kinzig A (2004) Resilience, adaptability and transformability in social-ecological systems. Ecol Soc 9(2)

Chapter 20
Strengthening Community Resilience to Reduce Barriers to Economic Participation During a Pandemic and a Climate Crisis

Elizabeth Mattiuzzi

Abstract Decisions made by multiple local and regional entities shape individual and household economic participation. One way to measure "community resilience" is through understanding an individual's or household's capacity to withstand shocks such as a pandemic or a natural disaster through continued participation in their regional economy. Yet discourse on community resilience often focuses on individual households, neighborhoods, or jurisdictions, rather than regions. This essay first defines community resilience in a regional context. Second, it discusses what different players in the community development (CD) field have done to try to address the COVID-19 pandemic's impact on individuals and households in low- and moderate-income communities and communities of color. Third, it proposes that regional collaboration holds promise for strengthening community resilience in a way that is transformative and addresses underlying vulnerabilities; two multi-site technical assistance programs that helped spur regional networks around social equity and sustainability principles provide examples of how policymakers and the CD field can further regional collaborations. Finally, this essay identifies opportunities to chart an equitable pandemic recovery that strengthens community resilience through regional collaboration.

Keywords Coummunity resilience · Inequality · Economic participation · Community

Where we live, work, go to school, and participate in civic and social life rarely fits neatly within the boundaries of a single city or county. Rather, we tend to do most of these things across a metropolitan area or "region." Decisions made by multiple

---

Views expressed do not necessarily represent those of the Federal Reserve Bank of San Francisco or the Federal Reserve System.

E. Mattiuzzi (✉)
Federal Reserve Bank of San Francisco, San Francisco, CA 94105, USA
e-mail: Elizabeth.Mattiuzzi@sf.frb.org

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_20

local and regional entities shape everything from an individual's or household's search for an affordable place to live to their search for affordable childcare within a reasonable distance from work, school, and cultural and natural amenities (Dreier et al. 2000). Job, housing, and transportation options in a regional spatial context shape individual and household economic participation (Chapple 2015). One way to measure "community resilience" is through understanding an individual's or household's capacity to withstand shocks such as a pandemic or a natural disaster through continued participation in their regional economy. Yet discourse on community resilience often focuses on individual households, neighborhoods, or jurisdictions, rather than regions (Chenoweth and Stehlik 2001; Godschalk 2003; Norris et al. 2008). This essay will first define community resilience in a regional context. Second, it will discuss what different players in the community development (CD) field have done to try to address the COVID-19 pandemic's impact on individuals and households in low- and moderate-income communities and communities of color. Third, it will propose that regional collaboration holds promise for strengthening community resilience in a way that is transformative and addresses underlying vulnerabilities; two multi-site technical assistance programs that helped spur regional networks around social equity and sustainability principles provide examples of how policymakers and the CD field can further regional collaborations. Finally, this essay identifies opportunities to chart an equitable pandemic recovery that strengthens community resilience through regional collaboration.

20.1 Community Resilience in a Regional Economy

Low- and moderate-income (LMI) people and people of color (PoC) face the largest historical and present barriers to participation in the economy, negatively impacting their wealth, wellbeing, and contributions to economic activity. These barriers hinder "community resilience," a term this essay will use to describe the ability of individuals and families to withstand an economic shock such as the COVID-19 pandemic while continuing to participate fully in the regional economy. A related concept is regional economic resilience, or the ability of a metropolitan area's economy to withstand economic or other shocks (Pendall et al. 2007; Hill et al. 2012). As Federal Reserve Bank of San Francisco President Mary Daly has noted, "In both health and economic terms, the costs [of the pandemic] have fallen most heavily on those who are least able to bear them. Low-income communities have been disproportionately burdened by COVID-19 (Daly 2020)." People of color are disproportionately employed in industries that have seen the largest job losses and in "essential" employment categories that involve high contact, and with it virus transmission potential (U.S. Bureau of Labor Statistics 2020; Chaganti et al. 2020). Unemployment has been worse during the pandemic for people with low education levels, and low-wage jobs have not recovered to the extent that high-wage jobs have (Daly et al. 2020; Long 2020). For many, a return to the status quo would still entail significant barriers to full local and regional economic participation, which is why this essay will use the term "community resilience" as interchangeable with the idea of "transformative adaptation," or a recovery that leaves vulnerable or marginalized populations with a better, not just the same, ability to cope with shocks and stresses (Keenan and Mattiuzzi 2019). Before the pandemic, the "racial wealth gap," or the difference in total assets between whites and nonwhite groups, even adjusted for education, was large (Bhutta et al. 2020).

Wealth is the single biggest predictor of people's ability to withstand a shock such as an illness, loss of a job, or a natural disaster (Ricketts and Boshara 2020). For most Americans, even a small unexpected expense would present a major financial hardship (Board of Governors of the Federal Reserve 2019). Homeownership is the main way middle- and lower-middle-class Americans build wealth that can be used to access, among other things, higher education (Kuhn et al. 2020). Generations of people of color, especially African Americans, were excluded from homeownership by discriminatory lending and sales practices (Rothstein 2017; Jackson 1987). Black households in particular lost housing wealth in the Great Recession (Kuhn et al. 2020). Additionally, employment, already lower, returned at a slower pace post-Great Recession for nonwhites than for whites (Nunn et al. 2019). Today, discrimination in home valuations and disparities in municipal resource allocation continue to dampen Black and PoC wealth creation through homeownership (Howell and Korver-Glenn 2020; Trounstine 2018). Additionally, zoning practices keep well-resourced neighborhoods, school districts, cities, and entire counties off limits, segregating them by income and race within regions by excluding more affordable multi-family and small lot housing types (Schafran 2018; Mattiuzzi and Weir 2020).

Planning and economic development decisions made by cities and counties shape access to opportunity. "Opportunity" in a regional context includes access to good schools and childcare, healthcare facilities, stable housing, clean air, open space, healthy food, low-stress commutes, small business capital, and stable employment (Chapple 2015). In the context of climate impacts, community resilience additionally includes having places to live that minimize the impact of flooding, drought, extreme heat, fires, and other shocks and stresses exacerbated by climate change (Méndez 2020). A diversified regional economy is a contributor to community resilience, a fact that the pandemic has made more visible (Chapple 2015, pp 169–170; Benner and Pastor 2016). Indeed, metropolitan areas that are heavily dependent on low-wage service jobs, such as in the tourism sector, have had the largest disruptions to their economies, including the highest unemployment rates, during the pandemic, causing ripple effects for communities (U.S. Bureau of Labor Statistics). Traditionally, local economic development officials have sought to promote the growth of a single industry or attract a single large employer (Campbell 1996). However, such "smokestack chasing" can leave regions vulnerable to potentially-lasting job losses in a recession (Dissart 2003; Izraeli and Murphy 2003; Berg et al. 2012). In the modern economy, having a diverse workforce, diverse firms, as well as making investments in quality of life infrastructure such as transit, parks, and bike/pedestrian trails promote regional resilience in a recession more than, for example, subsidies to attract a single large employer (Quigley 1998; Florida 2003).

Local decisions that embody "regional thinking" can help expand opportunity and reduce the drawbacks of parochialism. Removing barriers to social equity, such as local restrictions on multi-family housing construction, that contribute to racial and income segregation, is associated with greater prosperity across the entire regional economy (Benner and Pastor 2015). Investing in public transportation, typically a regional endeavor, connects people to jobs and commerce and lowers carbon emissions and other co-pollutants by encouraging reduced use of cars (Sanchez 1999). Improving access to sidewalks, bike lanes, and green spaces makes public transportation more accessible, improves public health through physical activity, and reduces hazards such as urban heat islands (Cervero 2001; Handy et al. 2002; Keith et al. 2020). Regional government entities often provide support for dense development at the local level, which can encourage reduced car use and increased walking and biking, regardless of transit infrastructure (Chatman 2013). Community-oriented design processes and anti-displacement measures can make these strategies more equitable (Innes and Booher 2010). Yet each region and its individual communities have distinct needs and histories, and increasing community resilience is a long-term endeavor that is not one-size-fits-all.

20.2 CD Field Pandemic Responses to Strengthen Individual and Household Resilience

The COVID-19 pandemic exposed issues that, addressed on a longer-term basis from a regional perspective, could help promote lasting, transformative community resilience. The pandemic has challenged many of the supports of basic individual stability with regard to health, housing, employment, and individual finances. The Community Development team at the Federal Reserve Bank of San Francisco has been monitoring the CD field's response to the pandemic in the 12th Federal Reserve District.[1] The largest and most critical responses to the pandemic have been the emergency measures taken by states and the federal government to supplement income, payrolls, and eviction protections during the crisis. In addition, banks, nonprofits, and others in the CD field, such as housing organizations, have worked to bolster the resilience of people impacted by the pandemic, particularly LMI and PoC communities.

Access to financial services is an important part of individual resilience. Banks that the SF Fed CD team spoke with early in the pandemic reported working directly with customers, as well as with local philanthropic organizations and

[1] The 12th Fed District includes Alaska, Arizona, California, Hawaii, Idaho, Nevada, Oregon, Utah, Washington, American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands.

community development financial institutions (CDFIs) to provide pandemic relief to individuals and small businesses (Shrimali 2020a, b). Banks contacted during the shutdown in March-April 2020 indicated working to expedite small dollar loans and reducing barriers to withdrawing or depositing funds that would normally carry limitations or penalties (id.). Increases in the accessibility of electronic banking services and financial education for customers, a fix used by banks during the pandemic, could provide a long-term boost to individual financial resilience if left in place.

Nonprofit organizations that operate in communities are a key support to individual and community resilience. Nonprofits faced significant disruption to their operations and their finances during the early months of the pandemic, even as demand for their services increased, according to a survey conducted by the Federal Reserve System (Federal Reserve System 2020; Choi et al. 2020). The Small Business Administration and the Federal Reserve have made loans available to nonprofits during the pandemic. Banks and philanthropic organizations have provided flexibility to grantees to use funds for general operations to help nonprofits stay afloat. Yet, challenges remain. According to interviews and outreach conducted by the SF Fed CD team, organizations with in-person oriented missions such as providing health and domestic violence related services had trouble reaching clients during the shutdown. Purchasing personal protective equipment as they reopen has added to their expenses. As with banking services, some nonprofits have been able to expand online services, but the “digital divide” makes it hard to reach clients who lack good access to internet, devices, and the skills necessary to use them. One way to secure nonprofits in their role as supporters of community resilience for the long term is to stabilize their real estate conditions, particularly in larger metropolitan areas with strong real estate markets (Hodge et al. 2020). Although not all nonprofits are positioned to purchase space, negotiating leases with nominal rents from public sector landlords and sharing space with complementary organizations are some of the strategies that nonprofits use to secure their operating space (id.).

Housing instability, which can harm individual resilience through cascading impacts on personal finance and health, has been exacerbated by the pandemic. Housing organizations that the SF Fed CD team interviewed in July 2020 reported that LMI and PoC renters and homeowners have been seeking assistance from nonprofit counselors and banks (Hodge and Mattiuzzi 2020). Loan forbearance implemented by banks has been critical to helping many LMI homeowners weather income losses, although it created confusion for some and disruption for those who received it without having requested it (id.). Federal, state, and local eviction moratoria helped stabilize households, but have not been applied evenly, leaving some still facing evictions (National Housing Law Project 2020). Similarly, rental assistance did not reach everyone in need (Hodge and Mattiuzzi 2020). Housing organizations interviewed reported a need for tenant legal assistance and tenant protections, as well as support for mom and pop landlords (id.). At the same time, increasing employment levels and wages and providing more affordable housing options will also be important to reducing housing instability in the long run.

Furthermore, local governments will need fiscal support to avoid cuts to services as they face lost revenue from property and sales taxes during the pandemic.

Banking services, public- and nonprofit-provided social services, and stable housing are just a few of the supports to individual and household stability that enable full participation in the workforce and the regional economy. Yet, understandably, much of the pandemic response has been a stopgap for individuals and families. Regionally-minded efforts by local governments, regional collaboration, and policies that reduce inequities could help promote community resilience that improves, not just stabilizes, conditions for LMI and PoC communities.

20.3 Community Resilience at a Regional Scale

Community resilience is built upon the regional context in which people live. Do they have access to good jobs, hospitals and schools in their town or a nearby town? Can they afford a safe place to live with a reasonable commute? Is their home/business safe from flooding, fires, and other disasters? All of these foundations of community resilience are affected by decisions made by multiple institutions in a metropolitan area. On the flipside, community resilience can be constrained by parochialism. While there is certainly work to be done on the regulatory, fiscal, and legislative side of these issues at the state and federal levels, there is also a role for regional collaboration in addressing community resilience. Many metropolitan areas have existing networks that cut across different sectors (e.g., community groups, nonprofits, government, business, health care providers, universities, and others) and across issues areas that affect community resilience at a regional scale (e.g., transportation, housing, economic development, and community development) (Payton Scally et al. 2020). These networks typically arise from state or federal actions or philanthropic leadership, and in some cases involve technical assistance (TA) and opportunities for local actors to learn from participants in other regions (id.). Existing regional collaborative networks could pivot to or provide a model for addressing resilience in the context of equitable pandemic recovery. Support and coordination from higher levels of government help promote regional networks and regionally-minded policies (Mattiuzzi 2020). Two multi-site experiments in spurring community resilience through regional collaboration provide lessons for adapting or creating networks to address equitable pandemic recovery and the ongoing climate crisis.

Cross-sector regional collaboration can play an important role in promoting community resilience, as well as in transforming the status quo for LMI people and communities of color. A federally-funded experiment in cross-sector collaboration presents a model for equitable pandemic recovery efforts that support regional and individual resilience. The Sustainable Communities Initiative (SCI) regional planning grant program (2010–2015) demonstrated that an incentive grant for regional goal-setting could produce long-term dialogue and policy change in a metropolitan area, even one without previous experience with this type of work (Mattiuzzi and

Chapple 2020). It was one product of a partnership by three federal agencies (HUD, DOT, and EPA) that each have a footprint in regions to explore ways to have their actions and funding better support regional goals and not work at cross purposes (Marsh 2014). In contrast to most federal and state funding sources that go to single jurisdictions, the grant required participation from across city and county lines, as well as other partners from philanthropy, universities, business, and community organizations that often do not cross paths (Chapple 2015). Seventy-four regions across the U.S. received the SCI regional planning grant. In one rural region, a multi-county economic development agency used their regional planning grant to kickstart work by philanthropy and local government to help low-income seniors weatherize their homes, improving their financial and climate resilience (Mattiuzzi and Chapple 2020). Cross-sector partners in another rural region, with assistance from the grant program, improved collaboration on gathering and sharing data on the gaps in access to affordable transportation and housing for low-wage agricultural and food processing workers in the region, many of whom are Latino (id.). The grant increased shared understandings among local/regional actors through its planning and data collection requirements as well as through data sharing from HUD (id.). With the right incentives and open-mindedness about what different organizations and people with different job descriptions can contribute to strengthening regional resilience, this type of regional collaboration can be adapted to COVID recovery.

Regional collaboration can surface barriers to economic participation and build connections between groups that work on different facets of resilience. A philanthropy-led experiment in regional resilience brought together grassroots community organizations with nonprofit organizations that operate as both CDFIs and TA providers in their regions (Choi 2019). The Strong, Prosperous, and Resilient Communities Challenge (SPARCC), which the SF Fed CD team was on the organizing team for, established cross-sector collaborative networks in six regions. A key goal of the initiative was for the participants to develop relationships and skills to impact policies in their region and propose fundable projects to the CDFIs. Examples include retrofitting and preserving affordable homes and financing accessory dwelling units (ADUs) for low-income homeowners to rent to low-income tenants. SPARCC made regionally-specific data on neighborhood change accessible to regionally-based groups. Through dialogue among the organizations representing each region, the initiative came to focus on housing stability as seen through the initiative's starting lenses of race, health, and climate. Through critique and discussion of mapped data on housing, race, and other variables, regional networks came to shared understandings of how investment and disinvestment, particularly related to environmental resources and climate impacts, contribute to the displacement of LMI and PoC residents from their homes and neighborhoods (Culbertson and Roy Ellias 2020). Participants provided feedback to university researchers on the assumptions they used when mapping data on displacement and raised examples of climate gentrification in their local and regional context (Cash et al. 2020; Keenan et al. 2018). As an example of regional collaboration, SPARCC is notable for its movement-building focus; participants from one region helped pass new local "tenant/community opportunity to purchase" housing preservation policies, a concept explained below.

20.4 Charting an Equitable Recovery

Community resilience as viewed through a regional lens underpins a holistic understanding of the structural barriers that individuals and communities face in achieving full economic participation. Regional collaborations, such as those supported by the federal SCI regional planning grant and the philanthropic SPARCC initiative, can make existing resources, such as state and federal funding, have a greater impact and complement one another. In many regions, such collaboration would not require starting from scratch. Existing regional networks face an opportunity to pivot to equitable pandemic recovery. Such a pivot might entail a regional network focusing on a single barrier to economic participation, such as access to childcare, or it might focus on multiple policy issues that affect community resilience. In either case, a willingness by individuals and institutions to see their job description or mandate as interconnected within a metropolitan region can help further economic, social, and climate resilience. This is particularly true for government agencies and elected officials whose priorities tend to be siloed by policy area or geographic boundaries. Indeed, for some regions with unsustainable housing costs and mega-commutes, the vision of local officials needs to stretch to neighboring regions.

Making relevant data more accessible to local actors would be a logical focal point for public and nonprofit institutions that play a convening role in regions as they work towards promoting resilience in the context of the pandemic and climate change. Locally- and regionally-disaggregated data can support local government and advocates working towards transformative community resilience. As in the examples of the SCI and SPARCC regional networks, local and regional data help clarify what needs are on the ground and can be part of a process of different groups and institutions coming to shared understandings of problems and potential solutions. Yet public sector administrative data and commercial data, such as on climate risk, are often difficult or expensive to access (Engelhardt and Fedorowicz 2019; Keenan 2019). Smaller local government entities often do not have the capacity to make data as basic as how parcels in their city are zoned available online or in an easily translated format. Even with widely-available data collected by federal agencies such as the Census Bureau or the Department of Labor, regional nonprofits and public sector employees may not have the capacity to wade through it in a timely manner. Academic, policy, and research organizations, such as the Urban Displacement Project at UC Berkeley, PolicyLink, the Urban Institute, and the Evictions Lab at Princeton do some of this work, i.e., to make relevant local/regional data about inequality, schools, housing, or climate risk, for example, available to partners in regions who can use it in their work or their advocacy.

However, much data about climate risk and the rental market, for example, that could support resilience efforts during or after the pandemic is only available from commercial sources.

Preserving affordable housing, an endeavor that is often supported by cross-sector regional partnerships, is an important strategy for increasing community resilience. Some advocates in the community development field anticipate a potential opportunity for affordable housing operators or community land trusts to purchase rental properties that come on the market amidst the pandemic and stabilize/subsidize rents at current or below-market levels (Abrams 2020). Properties with a small and medium number of units owned by mom and pop landlords are a traditional source of unsubsidized, market rate "affordable" housing (Hyun Choi and Goodman 2020). With mom and pop landlords experiencing missed payments from tenants and increased vacancies, as well as falling rents across the board, some of these properties could potentially come on the market (Hyun Choi and Goodman 2020; Young 2020). New owners making upgrades and bringing rents up to market rates can lead to displacement of existing tenants. In some large metro areas, including Washington D.C., San Francisco, and Oakland, so-called tenant/community opportunity to purchase act laws (known by their acronyms TOPA or COPA), aid efforts to preserve unsubsidized affordable housing by giving affordable housing operators or tenants a window to purchase the building (Mattiuzzi 2019; Yellen 2020). However, technical assistance and capital are needed to make these purchases in a short time frame, rehabilitate buildings, and stabilize/subsidize rents (Yellen 2020). Cross-sector regional collaborations have supported raising flexible yet patient capital for affordable housing acquisition-rehab (Mattiuzzi 2019). In a similar spirit, a new California law (Senate Bill 1079, authored by State Senator Nancy Skinner) prohibits bundling of sales of foreclosed properties and provides a window of time for tenants, owner occupants, or nonprofits to purchase them (East Bay Times 2020). The law is motivated by a desire to prevent a repeat of the Great Recession, when investor-owned companies purchased numerous foreclosed homes, removing them from the market for individuals and families to purchase and build wealth (id.).

20.5 Community Resilience Starts with Regional Thinking

Regional collaboration works best when local actors determine the specific focus areas and solutions, even within a broader state/federal/philanthropy-driven framework. Sustained funding, specific goals, and opportunities to learn from national experts and peer regions lend vitality to regional networks. In late 2020, the needs are clear—for an equitable pandemic recovery that promotes community resilience and for bold actions towards transformative climate adaptation—even if the exact local/regional issues and solutions need refining. The dust has not yet settled on the degree to which commute patterns to suburban tech hubs and downtown business districts will be permanently altered by increasing work-from-home flexibility for workers in information-based industries, but a return to the status quo is unlikely. Hospitality, food service, and retail industries, which are drivers of regional economies, will likely need support and rethinking as altered commuting, business travel, and online shopping reshape consumer behavior. A lack of access to fast internet for working and studying at home spans rural and urban LMI and PoC communities (Andreason et al. 2020; Sablik 2020). Mental health issues under pandemic conditions and cracks in the childcare network have taken on a new urgency (Choi 2020; Shrimali 2020a, b). At the same time, the unremittingness of fire season in the 12th Federal Reserve District amidst the pandemic has served as a reminder that climate-related resilience challenges remain (Aylward and Oliveira 2020). The need for protection for farmworkers on poor air quality days and the need for home retrofits in the face of extreme heat and smoke in the 12th District are both resilience challenges.

Regional collaboration in support of community resilience does not require a whole new playbook, but it requires a sustained effort and a willingness to build cross-sector, cross-jurisdictional relationships and to see the equity and resilience angles that are missing from existing frameworks and policies. Such an effort should aim to be transformative, increasing equity and resilience for LMI and PoC communities, thereby strengthening the entire regional economy. Exclusionary zoning, fragmented tax bases, and the limited authority and resources of regional government entities are just a few of the structural barriers to coherent regional policy on social, economic, and environmental issues that impact community resilience. Regional collaborative networks have limitations; understandably, the institutions and people that participate in them move on to other issues as incentives lapse or other local priorities arise. Yet at a moment when there is an uncommon level of shared interest arising from the urgency of pandemic response and recovery, as well as climate risks, coming together across the boundaries of institutions, jurisdictions, and traditionally-separate policy issues is essential to removing barriers to full economic participation, especially for LMI and PoC communities.

Disclaimer: The views and opinions expressed in this article are those of the individual authors and not those of the U.S. Federal Reserve Bank.

References

Abrams A (2020) Lessons from the last housing crisis: how to get control of properties. Shelterforce 09/17/2020. https://shelterforce.org/2020/09/17/lessons-from-the-last-housing-crisis/

Andreason S, Pearse H, Sarah M, de Zeeuw M (2020) The digital divide and the pandemic: working from home and broadband and internet access. Federal Reserve Bank of Atlanta Workforce Curr 2020-06. https://doi.org/10.29338/wc2020-06

Aylward J, Oliveira LE (2020) Rising wildfire risk for the 12th District economy. Federal Reserve Bank of San Francisco Econ Lett 2020-19. https://www.frbsf.org/economic-research/publications/economic-letter/2020/july/rising-wildfire-risk-for-12th-district-economy/

Benner C, Pastor M (2015) Equity, growth, and community: What the nation can learn from America's metro areas. University of California Press, Berkeley. https://doi.org/10.1525/luminos.6

Benner C, Pastor M (2016) Whither resilient regions? equity, growth and community. J Urban Aff 38(1):5–24. https://doi.org/10.1111/juaf.12194

Berg A, Ostry JD, Zettelmeyer J (2012) What Makes Growth Sustained? J Dev Econ 98(2):149–166. https://doi.org/10.1016/j.jdeveco.2011.08.002

Bhutta N, Chang AC, Dettling LJ, Hsu JW, Hewitt J (2020) Disparities in wealth by race and ethnicity in the 2019 survey of consumer finances. Board of Governors of the Federal Reserve FEDS Notes 9/28/2020. https://www.federalreserve.gov/econres/notes/feds-notes/disparities-in-wealth-by-race-and-ethnicity-in-the-2019-survey-of-consumer-finances-20200928.htm

Board of Governors of the Federal Reserve (2019) Report on the Economic Well-Being of U.S. Households in 2018–2019. https://www.federalreserve.gov/publications/2019-economic-well-being-of-us-households-in-2018-dealing-with-unexpected-expenses.htm

Campbell S (1996) Green Cities, Growing Cities, Just Cities? urban planning and the contradictions of sustainable development. J Am Plan Assoc 62(3):296–312. https://doi.org/10.1080/01944369608975696

Cash A, Mattiuzzi E, Driscoll A, Chapple K, Roy Elias R, Zuk M (2020) Building a national narrative of anti-displacement strategies: key takeaways from SPARCC regions. UC Berkeley Center for Community Innovation; SPARCC; and Urban Displacement Project, University of California Berkeley. https://www.urbandisplacement.org/sites/default/files/images/building_a_national_narrative_october_2020-converted.pdf

Cervero R (2001) Walk-and-ride: factors influencing pedestrian access to transit. J Public Transport 3(4):1–23. https://doi.org/10.5038/2375-0901.3.4.1

Chaganti S, Graves E, Higgins A, Mattingly M, Savage S, Tonsberg C (2020) The effects of the novel coronavirus pandemic on service workers in New England. Federal Reserve Bank of Boston Community Dev Issue Brief 2020-1. https://www.bostonfed.org/-/media/Documents/Community%20Development%20Issue%20Briefs/cdbrief12020.pdf

Chapple K (2015) Planning sustainable cities and regions: towards more equitable development. Routledge, New York

Chatman DG (2013) Does TOD need the T? on the importance of factors other than rail access. J Am Plan Assoc 79(1):17–31. https://doi.org/10.1080/01944363.2013.791008

Chenoweth L, Stehlik D (2001) Building resilient communities: social work practice and rural queensland. Aust Soc Work 54(2):47–54. https://doi.org/10.1080/03124070108414323

Choi L (2019) Testing our hypotheses on equitable development: midcourse learning and adapting through SPARCC. Federal Reserve Bank of San Francisco Community Dev Res Brief 2019-01. https://doi.org/10.24148/cdrb2019-01

Choi L (2020) The mental health implications of COVID-19 on low-income communities and communities of color. Federal Reserve Bank of San Francisco Community Dev Res Brief 2020-2. https://doi.org/10.24148/cdrb2020-02

Choi L, Mattiuzzi E, Shrimali BP (2020) Impacts of COVID-19 on nonprofits in the Western United States. Federal Reserve Bank of San Francisco Community Dev Res Brief 2020-3. https://doi.org/10.24148/cdrb2020-03

Culbertson D, Roy Ellias R (2020) Driving national anti-displacement strategies from the ground up: key takeaways from SPARCC and urban displacement project's gentrification and displacement analysis. SPARCC. https://www.sparcchub.org/2020/11/10/driving-national-anti-displacement-strategies-from-the-ground-up/

Daly MC (2020) We Can't Afford Not to. [Speech delivered at the National Press Club 6/15/2020]. https://www.frbsf.org/our-district/press/presidents-speeches/mary-c-daly/2020/june/we-cant-afford-not-to/

Daly MC, Buckman SR, Seitelman LM (2020) The unequal impact of COVID-19: Why education matters. Federal Reserve Bank of San Francisco Econ Lett 2020-17. https://www.frbsf.org/economic-research/publications/economic-letter/2020/june/unequal-impact-covid-19-why-education-matters/

Dissart JC (2003) Regional economic diversity and regional economic stability: research results and agenda. Int Reg Sci Rev 26(4):423–446

Dreier P, Swanstrom T, Mollenkopf JH (2000) Place matters: metropolitics for the twenty-first century, 2nd edn. University Press of Kansas, Lawrence

East Bay Times (2020) Nancy Skinner's Bill would help tenants, groups, cities buy vacant homes. East Bay Times 2/20/2020. https://www.eastbaytimes.com/2020/02/20/in-brief-skinners-bill-would-help-tenants-groups-cities-buy-vacant-homes/

Engelhardt W, Fedorowicz M (2019) Guidance on collecting administrative data for pay for success projects: five lessons from a training and technical assistance engagement. Urban Institute. https://www.urban.org/research/publication/guidance-collecting-administrative-data-pay-success-projects

Federal Reserve System (2020) Perspectives from main street: the impact of COVID-19 on communities and the entities serving them. April 2020. https://www.frbatlanta.org/-/media/documents/community-development/publications/federal-reserve-system-resources/05/04/perspectives-from-main-street-the-impact-of-covid-19-on-communities.pdf

Florida R (2003) Cities and the creative class. City Community 2(1):3–19. https://doi.org/10.1111/1540-6040.00034

Godschalk DR (2003) Urban hazard mitigation: creating resilient cities. Nat Hazards Rev 4 (3):136–143. https://doi.org/10.1061/(ASCE)1527-6988(2003)4:3(136)

Handy SL, Boarnet MG, Ewing R, Killingsworth RE (2002) How the built environment affects physical activity: views from urban planning. Am J Prev Med 23(2):64–73. https://doi.org/10.1016/S0749-3797(02)00475-0

Hill E, St T, Clair HW, Wolman H, Atkins P, Blumenthal P, Ficenec S, Friedhoff A (2012) Economic shocks and regional economic resilience. In: Weir M, Pindus N, Wial H, Wolman H (eds) Urban and regional policy and its effects. The Brookings Institution, Washington, D.C.

Hodge E, Mattiuzzi E (2020) COVID-19 impacts on housing stability in the twelfth federal reserve district. Federal Reserve Bank of San Francisco Community Dev Res Brief 2020-6. https://doi.org/10.24148/cdrb2020-06

Hodge E, Kim J, Mattiuzzi E (2020) Holding space: underlying real estate conditions for nonprofits in the Los Angeles Region. Federal Reserve Bank of San Francisco Community Dev Res Brief 2020-4. https://doi.org/10.24148/cdrb2020-04

Howell J, Korver-Glenn E (2020) The increasing effect of neighborhood racial composition on housing values, 1980–2015. Soc Probl. https://doi.org/10.1093/socpro/spaa033

Hyun Choi J, Goodman L (2020) Mounting pressures on mom-and-pop landlords could spell trouble for the affordable rental market. Urban Institute Urban Wire. Accessed at 10 Nov 2020, https://www.urban.org/urban-wire/mounting-pressures-mom-and-pop-landlords-could-spell-trouble-affordable-rental-market

Innes JE, Booher DE (2010) Planning with complexity: an introduction to collaborative rationality for public policy, 1st edn. Routledge, New York

Izraeli O, Murphy KJ (2003) The effect of industrial diversity on state unemployment rate and per capita income. Ann Reg Sci 37(1):1–14. https://doi.org/10.1007/s001680200100

Jackson KT (1987) Crabgrass frontier: the suburbanization of the United States. Oxford University Press, Oxford

Keenan JM (2019) A climate intelligence arms race in financial markets. Science 365(6459): 1240–1243. https://doi.org/10.1126/science.aay8442

Keenan JM, Mattiuzzi E (2019) Climate adaptation investment and the community reinvestment act. Federal Reserve Bank of San Francisco Community Dev Res Brief 2019-5. https://doi.org/10.24148/cdrb2019-05

Keenan JM, Hill T, Gumber A (2018) Climate gentrification: from theory to empiricism in Miami-Dade County, Florida. Environ Res Lett 13(5): https://doi.org/10.1088/1748-9326/aabb32

Keith L, Meerow S, Wagner T (2020) Planning for extreme heat: a review. J Extreme Events 6:2050003. https://doi.org/10.1142/S2345737620500037

Kuhn M, Schularick M, Steins UI (2020) Income and wealth inequality in America, 1949–2016. J Polit Econ 128(9):3469–3519. https://doi.org/10.1086/708815

Long H (2020) The recession is over for the rich, but the working class is far from recovered. Washington Post. Accessed at 13 Aug 2020 from https://www.washingtonpost.com/road-to-recovery/2020/08/13/recession-is-over-rich-working-class-is-far-recovered/

Marsh DS (2014) The sustainable communities initiative: collective impact in practice. Federal Reserve Bank of San Francisco Community Invest 26(1):30–36. https://www.frbsf.org/community-development/publications/community-investments/2014/march/sustainable-communities-initiative-collective-impact-practice/

Mattiuzzi E (2019) Funds for kickstarting affordable housing preservation and production: lessons for new investors. Federal Reserve Bank of San Francisco Community Dev Res Brief 2019-02. https://doi.org/10.24148/cdrb2019-02

Mattiuzzi E (2020) The role of county-level agencies in coordinating local climate planning in California. In: Elizabeth D (ed) Transportation, land use, and environmental planning. Elsevier, Cambridge, MA, pp 469–495. https://doi.org/10.1016/B978-0-12-815167-9.00021-9

Mattiuzzi E, Chapple K (2020) Epistemic communities in unlikely regions: the role of multi-level governance in fostering regionalism. J Plan Educ Res:1–15. https://doi.org/10.1177/0739456X20937287

Mattiuzzi E, Weir M (2020) Governing the new geography of poverty in metropolitan America. Urban Aff Rev 56(4):1086–1131. https://doi.org/10.1177/1078087419834075

Méndez MA (2020) Climate change from the streets: how conflict and collaboration strengthen the environmental justice movement. Yale University Press, New Haven

National Housing Law Project (2020) Stopping COVID-19 evictions survey results. https://www.nhlp.org/wp-content/uploads/Evictions-Survey-Results-2020.pdf

Norris FH, Stevens SP, Pfefferbaum B, Wyche KF, Pfefferbaum RL (2008) Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. Am J Community Psychol 41(1–2):127–150. https://doi.org/10.1007/s10464-007-9156-6

Nunn R, Parsons J, Shambaugh J (2019) Race and underemployment in the US labor market. Brookings Institution Up Front 8/1/2019. https://www.brookings.edu/blog/up-front/2019/08/01/race-and-underemployment-in-the-u-s-labor-market/

Payton S, Lydia Lo C, Pettit KLS, Anoll C, Scott K (2020) Driving systems change forward: leveraging multisite, cross-sector initiatives to change systems, advance racial equity, and shift power. Urban Institute and Federal Reserve Bank of San Francisco Open Source Solutions 8:1–10. Accessed at https://www.frbsf.org/community-development/files/driving-systems-change-forward-executive-summary.pdf

Pendall R, Foster KA, Cowell M (2007) Resilience and regions: building understanding of the metaphor. In: Working Paper 2007-12 of UC Berkeley Institute of Urban and Regional Development and MacArthur Foundation Research Network on Building Resilient Regions. https://escholarship.org/content/qt4jm157sh/qt4jm157sh.pdf

Quigley JM (1998) Urban diversity and economic growth. J Econ Perspect 12(2):127–138. https://doi.org/10.1257/jep.12.2.127

Ricketts L, Boshara R (2020) Which families are most vulnerable to an income shock such as COVID-19? Federal Reserve Bank of St. Louis In the Balance 5/1/2020. https://www.stlouisfed.org/publications/in-the-balance/2020/families-most-vulnerable-to-income-shock

Rothstein R (2017) The color of law: a forgotten history of how our government segregated America. Liveright, New York

Sablik T (2020) Closing the digital divide. Federal Reserve Bank of Richmond Econ Focus 2020-3. https://www.richmondfed.org/-/media/richmondfedorg/publications/research/econ_focus/2020/q2-3/feature2.pdf

Sanchez TW (1999) The connection between public transit and employment: the cases of Portland and Atlanta. J Plann Assoc 65(3):284–296. https://doi.org/10.1080/01944369908976058

Schafran A (2018) The road to resegregation: Northern California and the failure of politics. University of California Press, Berkeley

Shrimali BP (2020a) Child Care, COVID-19, and our economic future. Federal Reserve Bank of San Francisco Community Dev Res Brief 2020-5. https://doi.org/10.24148/cdrb2020-05

Shrimali BP (2020b) What are banks doing to address the impacts of COVID-19 on LMI communities? Early approaches to addressing the crisis. Federal Reserve Bank of San Francisco Community Dev Res Brief 2020-1. https://doi.org/10.24148/cdrb2020-01

Trounstine J (2018) Segregation by design: local politics and inequality in American cities. Cambridge University Press, Cambridge

U.S. Bureau of Labor Statistics (2020) Local area unemployment statistics for metropolitan areas: monthly unemployment rate (Not Seasonally Adjusted) [Data set]. https://data.bls.gov/cgi-bin/dsrv?la

Yellen J (2020) Preserving affordability, preventing displacement, acquisition-rehabilitation of unsubsidized affordable housing in the bay area. Enterprise Community Partners. https://www.enterprisecommunity.org/download?fid=13693&nid=10252

Young C (2020) College-area rents are falling behind as schools move online. Zillow Res. Accessed at 16 Sept 2020 from https://www.zillow.com/research/college-area-rents-falling-behind-27951/

Chapter 21
Resilience for Whom? Insights from COVID-19 for Social Equity in Resilience

A. R. Siders and Logan Gerber-Chavez

Abstract The novel coronavirus (COVID-19) pandemic highlights the social equity concerns inherent in system-wide concepts of ‘community resilience.’ Resilience of the collective may overlook or even be achieved at the expense of the resilience of populations within the community. COVID-19 is inequitable with respect to exposure, severity, and response. It affects the ability of communities to respond to other challenges including natural hazards, mental health, and domestic violence. Resilience to the pandemic has proven to involve not only traditional metrics of public health and economic welfare but a wide range of concerns such as childcare and gender equity. The experiences of COVID-19, then, argue for a broad conceptualization of general resilience involving a wide range of issues but a narrow emphasis on individual experiences rather than community-level metrics. The pandemic could exacerbate inequalities if powerful or privileged groups leverage resources not available to all members of the community to maintain personal resilience. Pandemics and other slow-onset or aggregate hazards have historically had little influence on policy, but the global, long-term nature of COVID-19 and collective nature of responses such as lockdowns create potential for powerful individuals to pursue social reforms that will benefit all and lead to true community-wide resilience.

Keywords Social equity · Equitable resilience · Community resilience · COVID-19

A. R. Siders (✉) · L. Gerber-Chavez
Disaster Research Center, University of Delaware, Newark, DE, USA
e-mail: siders@udel.edu

A. R. Siders · L. Gerber-Chavez
Joseph R. Biden, Jr. School of Public Policy and Administration, University of Delaware, Newark, DE, USA

A. R. Siders
Department of Geography and Spatial Sciences, University of Delaware, Newark, DE, USA

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_21

21.1 Introduction

The novel coronavirus (COVID-19) pandemic has highlighted social justice and equity concerns in ways that invite re-consideration of community resilience, not as a relationship between system and hazard but as the ability of all individuals within a social system to thrive in the face of uncertainty and change. This re-framing requires a broader conceptualization of both the system, which is to be resilient, and the disturbance to which it is responding: the 'of what to what' described by Carpenter et al. (2001). It also requires explicit consideration of the question 'for whom.' A narrow response to these prompts is likely to overlook important aspects of equity, as COVID-19 is currently demonstrating.

Disaster scientists and practitioners know that disasters do not affect people equally and that response and recovery measures can exacerbate, rather than alleviate, social inequality (see, e.g., Douglas 2015; Howell and Elliott 2018; Siders 2018; Tierney 2006). Epidemiologists know similar patterns occur in pandemics. A 2008 study of influenza predicted that low-income and minority populations would have difficulty complying with social-distancing measures (Blendon et al. 2008), and Blumenshine et al. (2008) proposed that differences in social position (due to race, income, status) could cause disparities in exposure, sensitivity, and treatment that would result in unequal patterns of infection and mortality. These predictions were observed during the 2009 H1N1 influenza pandemic, when low-income people and people of color were more likely to be exposed and more likely to face complications and hospitalization (Quinn et al. 2011). Similar outcomes are being observed now in the COVID-19 pandemic (Lima et al. 2020; Mein 2020; Rogers et al. 2020; Timothy 2020).

The fact that repeated disasters and epidemics have not inspired social or policy change suggests that social inequity has a robust measure of resilience. In other words, it is resistant to change from external influences and likely to return to prior conditions once a stressor is removed. Narrow and conservative concepts of resilience can aggravate this tendency, as can behaviors by powerful and affluent populations who leverage their position and resources to preserve their own status quo (that is, to maintain their own resilience) rather than to transform social structures. By highlighting the connections between resilience and justice, the COVID-19 pandemic invites us to reconsider how we conceptualize community resilience and may provide an opportunity for transformation.

21.2 Contested Concepts of Resilience

Resilience is defined in many ways and at many scales (Walker and Cooper 2011; Aldunce et al. 2015; Hosseini et al. 2016; Keenan 2018). Ecological, engineering, and disaster concepts of resilience often emphasize the return of a system to pre-disaster conditions or maintenance of system traits (Holling 1973; Klein et al.

2003; Alexander 2013; Aldunce et al. 2015; Siders 2016). The United Nations International Strategy for Disaster Reduction, for example, defines resilience as the ability to "resist, absorb, accommodate to, and recover from the effects of hazards in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions" (UNDRR 2015).

Such conservative concepts of resilience, although useful in engineering and ecology, have been widely critiqued in their application to social systems because of their tendency to overlook power dynamics, social inequalities, and the potential benefits of transformation rather than preservation (Jerneck and Olsson 2008; Hayward 2013; MacKinnon and Derickson 2013; Matin et al. 2018). Maintaining the status quo means also maintaining the inequities present. Traits that resist change due to hazards may also resist change due to beneficial social movements. Although social definitions of resilience—frequently referenced as 'community resilience'—often allow for or encourage transformation, they struggle to distinguish between harmful changes—to be resisted—and beneficial transformations—to be promoted. Indeed, such distinction may be impossible in advance of change, but concepts of community resilience need to consider the potential for both adaptive and maladaptive outcomes.

Carpenter et al. (2001), in an effort to more clearly operationalize resilience, focused on the questions 'of what to what': what system is being resilient to what threat or change. Inherent in these questions are questions of scale. Ecological resilience could refer equally to the resilience of an ecosystem, a species, or an organism. It could address resilience to drought, pests, heat, frost, or a combination of the above. Similarly, social resilience can refer to a person, community, society, or humanity writ large, and could focus on the ability to rebuild damaged infrastructure, to maintain social ties or economic prosperity, or to display general resilience to change. Scale affects people's sense of equity and justice (Cooper and McKenna 2008), so defining the scale in question is critical for understanding or pursuing community resilience with equitable outcomes. Recognizing the importance of scale, the resilience literature often distinguishes between 'specific' resilience to a specific threat and 'general' resilience, a broader concept of community resilience, and notes that the two types of resilience may actually be in competition (investing in one may decrease the other) (see, e.g., Carpenter et al. 2012; Walker and Westley 2011). The COVID-19 pandemic has forced us to reconsider how we distinguish between specific and general resilience. That is, it requires us to reconsider how we define 'of what to what': whether our understanding of community resilience to the pandemic includes childcare and domestic violence or focuses on economic recovery for nations. Aspects of life such as childcare that are often deemed secondary or tangential concerns in disaster management have emerged in the pandemic as core issues.

21.3 Inequity in COVID-19 Pandemic

Although COVID-19 was initially hailed as the “great equalizer” for its potential to affect rich and poor, Black and white, the pandemic has shown itself to be as inequitable as other types of hazards (Kullar et al. 2020; Mein 2020; Timothy 2020) with respect to exposure, sensitivity, as well as response and recovery. In the COVID-19 context, exposure describes the likelihood of coming into contact with a disease (OSHA 2009); sensitivity refers to the severity of the disease and potential for unequal access to and quality of healthcare; and response and recovery includes the potential for protective measures to have unintended harmful consequences. Although we organize these as separate sections, there are significant interactions between elements.

21.3.1 Exposure

In the United States and United Kingdom, COVID-19 has disproportionately affected BIPOC (Black, Indigenous, and people of color) communities (Clark et al. 2020; Kullar et al. 2020; Mein 2020; Raisi-Estabragh et al. 2020; Rogers et al. 2020). Increased exposure appears to be related to factors such as employment, transportation, housing, and access to protective equipment. BIPOC individuals are less likely to have worked from home before the pandemic and more likely to work in an ‘essential’ field where they continue to interact in-person while other portions of the population shelter at home (Rogers et al. 2020). BIPOC individuals are also more likely to use public transportation, where social distancing and cleaning protocols are more difficult to maintain (Quinn et al. 2011). A survey by the American Public Transport Authority found that 31% of bus riders were Black and 21% Hispanic, despite representing only 13% and 17% of the population, respectively (Clark 2017). In New York City alone, by May 2020, 120 employees of the Metropolitan Transportation Authority had died from COVID-19 and nearly 4,000 had tested positive (Lancet 2020).

Low incomes can compound the challenges of employment and public transportation. Thirty percent of U.S. bus riders are from households with incomes below $15,000 and another 16% are from households making less than $25,000 (Clark 2017). For reference, the 2020 poverty rate in the United States is $12,760 for an individual and $26,000 for a household. A quarter of essential workers in the United States are estimated to come from low-income households (McCormack et al. 2020), and these workers may have few affordable alternatives to public transportation to reach their jobs. They may also face greater financial pressure to retain or obtain employment in essential fields, despite the risks. During the 2009 H1N1 pandemic, low-income workers were more likely to be employed in industries with high levels of in-person contact and limited sick leave (Quinn et al. 2011), and similar patterns appear to be present in the current pandemic.

Race intersects with other aspects of vulnerability that make BIPOC populations particularly at-risk (Crenshaw 1991). For example, Blacks account for 40% of the homeless population in the United States (HUD 2020), and homeless populations may face increased exposure to COVID-19 in crowded shelters (Lima et al. 2020; Tobolowsky et al. 2020). Similarly, Blacks are over-represented in U.S. prison populations (Monk 2019), and prison populations are particularly exposed to infectious diseases due to confined spaces, poor ventilation, and crowded facilities—threats that are present in prison populations worldwide (Gaillard and Navizet 2012; Le Dé and Gaillard 2017; Akiyama et al. 2020; Saloner et al. 2020). Prisons have been shown to be ill-prepared for multiple types of disasters, and COVID-19 does not appear to be an exception (Purdum and Meyer 2020).

Prisons demonstrate another aspect of COVID-19: how the pandemic has affected the ability of communities to respond to other natural hazards. For example, the spread of COVID-19 in California prisons has reduced the availability of inmates to fight wildfires, affecting the state's ability to address a severe fire season (Fuller 2020; Goodkind 2020). In other parts of the country, fewer people are volunteering to assist with sandbagging in preparation for floods or with debris clean up after storms or tornadoes for fear of being exposed to COVID-19 (see, e.g., Porter 2020; Reese 2020). Social distancing measures that improve resilience to the pandemic may simultaneously reduce resilience to other threats.

21.3.2 Sensitivity

COVID-19 affects some populations more severely than others. BIPOC individuals are more likely not only to contract COVID-19 but also to be hospitalized and to die of the disease or related complications (Akintobi et al. 2020; Kullar et al. 2020; Poteat et al. 2020; Rogers et al. 2020). Elderly people are more likely to have severe complications or higher mortality rates (Kang and Jung 2020) as are people with pre-existing conditions (Gold et al. 2020; Yang et al. 2020).

These are social justice and equity issues because social services (or lack thereof) contribute to the unequal distribution of these consequences. Chronic exposure to social and economic disadvantages may cause or exacerbate health issues and lead to disparities in health conditions, a phenomenon known as the 'weathering' hypothesis (Thomas 2006; Forde et al. 2019). Low-income and BIPOC communities experience higher rates of chronic medical conditions such as asthma that make COVID-19 even more severe (see, e.g., Beck et al. 2016). Additionally, chronic stress can produce wear and tear on the body, known as allostatic load (Thomas 2006), which can reduce the body's ability to combat new pressures, such as COVID-19.

BIPOC and immigrant populations are more likely to be living in multi-family or multi-generational housing, where physical distancing can be more challenging and elderly family members may be placed at greater risk from their working family members (Langellier 2020; Metzl et al. 2020). An estimated 18% of essential workers live in a household with at least one member over the age of 65 and one member without health insurance (McCormack et al. 2020). Having health insurance has been clearly demonstrated to lead to better health outcomes (Bovbjerg and Hadley 2007), but access to affordable health care, is not even across the United States: BIPOC individuals are more likely to be uninsured (Berchick et al. 2019; Rogers et al. 2020).

21.3.3 Response and Recovery

Measures taken to prevent or recover from disasters can exacerbate social inequality (see, e.g., Douglas 2015; Howell and Elliott 2018; Siders 2018; Tierney 2006), and COVID-19 is no exception. Actions taken to contain the pandemic, such as quarantines, lockdowns, and social distancing, affect peoples' livelihoods, which affects their ability to access food and maintain housing (Barker and Russell 2020; Kulish 2020). Social support systems that rely on donations (e.g., food banks) may have decreased capacity to serve those most at need (see, e.g., Kulish 2020). Temporary moratoria against evictions and foreclosures can alleviate immediate housing concerns but do not address the underlying or long-term risks, especially for low- and moderate-income families (see, e.g., MAPC 2020).

Social distancing measures and stay-at-home orders can also cause problems by disrupting social support systems. Domestic abuse rates have risen worldwide as people are forced to shelter with their abusers (Bradbury-Jones and Isham 2020; United Nations 2020; Usher et al. 2020). This is a common issue during disasters and post-disaster recovery (WHO 2005; Schumacher et al. 2010; Gearhart et al. 2018), as social support systems are disrupted and victims may need to rely more on their abuser for housing or provision of other basic resources. The long duration of the pandemic makes this an even greater concern. Similarly, individuals with mental health challenges may face additional pressures due to social isolation and disruption of medical and social support systems (Druss 2020; Gunnell et al. 2020). Social distancing can cause depression, insomnia, and anxiety; may be related to intrapersonal violence and increased alcohol consumption; and has raised concerns about potential for increased suicide rates as the pandemic drags on (Gunnell et al. 2020). Mental health support is inadequate in most countries even in non-disaster times, and the limited ability to access in-person support, coupled with concerns about privacy and accessibility of remote mental health care, can make treating these issues difficult.

Disrupted social systems also affect child and elder care. Families who relied on paid care for family members may no longer have access to those supports. This may exacerbate gender inequality, as females tend to take on more housework and caregiving responsibilities (Alon et al. 2020; Del Boca et al. 2020; Farré et al. 2020). Because men earn more on average and are more likely to work in essential services, men's jobs are often the ones preserved during a recession or financial hardship, which can compound gender divisions.

Inequalities in virtual education may reduce social mobility and exacerbate intergenerational wealth inequalities (Van Lancker and Parolin 2020). Income affects the ability of students to access consistent internet services, working laptops or computers, and video cameras and microphones that enable participation (Tinubu Ali and Herrera 2020). Students who are homeless or housing insecure may face particular challenges (Tinubu Ali and Herrera 2020), as may students who require accommodations that are more difficult to make online (Petretto et al. 2020).

21.4 Potential of COVID

There are, of course, myriad ways the pandemic and efforts to contain the pandemic affect people unequally and expose weaknesses in the existing social system. None of these challenges—racial inequality, domestic violence, mental health treatment, gender inequality, educational access—are caused by the pandemic; rather, they are ingrained in society and merely rise to the forefront when the system is strained. Other hazards and previous pandemics have underscored the same or similar inequities, and the fact that these have remained in place for decades or centuries suggests that the social systems creating inequity are highly resilient: resistant to change and likely to return to prior conditions once the strain is removed. The optimistic hope for the COVID-19 pandemic, then, is that it inspires or forces policymakers, practitioners, academics, and the public to reconsider what it means to invest in community resilience and to take action to inspire transformation as a means to challenge the inequitable status quo.

Disasters are often framed as opportunities. Sudden shock event, such as acts of terrorism, hurricanes, and wildfires, have been shown to create windows of opportunity for social change, when both political decision-makers and the public are aware of a need for change and motivated to take action (O'Donovan 2017; Ulibarri and Scott 2019). As Folke et al. note, "[a] resilient social-ecological system may make use of crisis as an opportunity to transform into a more desired state" (Folke et al. 2005, p. 441). Hurricane Katrina motivated changes in U.S. emergency management (Fugate 2011). Fukushima sparked conversations about improving nuclear safety (Blandford and Sagan 2016).

However, the potential for slow-onset hazards, such as a global pandemic, to inspire policy reform is less clear (Ulibarri and Scott 2019). Individual tragedies, like traffic-related deaths, rarely inspire policy reform, although they may do so in aggregate (O'Donovan 2017). The number of incidents, characteristics of the people affected, and rate of increase all affect the extent to which 'society' takes notice. The question of whether COVID-19 deaths and harms have reached a sufficient level to inspire policy change is yet to be answered. Previous pandemics, even major ones such as the 1918 'Spanish Flu' pandemic, have been found to exert relatively little long-term influence on policy change (Meen et al. 2016).

Nevertheless, there are a few reasons to believe the COVID-19 pandemic could lead to widespread social change. The first is that COVID-19's long duration and global spread transcend the average disaster pattern. Common hazards and bounded epidemics have a limited duration or narrow geographic scope. This allows people to rely on resources stocked up before the disaster or to access resources from outside the stressed area. They can rely on social networks outside the affected region to provide emotional or financial support. For example, remittances from migrant communities have played a significant role in financing disaster recovery in their home countries (Bragg et al. 2018). Donations, volunteers, and material can all be sourced from unaffected places. With the COVID-19 pandemic, few areas are unaffected, so the ability to rely on external resources or social support systems is extremely limited. In this way, COVID-19 shows how un-resilient societies are, where resilience is defined as self-reliance (UNDRR 2009; Aldunce et al. 2015).

Second, the global nature of the COVID-19 pandemic raises the geographic scope over which aggregation can occur (O'Donovan 2017) and highlights widespread, multi-sector failures to address the hazard. An isolated hurricane, wildfire, or epidemic might be dismissed in the public mind as an exception, a rare failure by a single agency, or a particularly extreme event. However, when an event affects an entire nation and multiple nations in similar ways, it becomes more apparent that the problem lies not with a single agency or actor but with the underlying social structure. The global nature of the pandemic also invites comparisons between communities, cities, states, and nations and allows citizens to see how others are handling the same crisis (Bremmer 2020; Gibney 2020). This creates a living laboratory, in which governments can experiment with COVID-19 responses and the results of the experiment are seen rapidly, which may raise the potential for novel policies to inform actions in other regions.

Third, although COVID-19 is not the 'great equalizer' sometimes mentioned by politicians (Timothy 2020), the effects of the pandemic and of lockdowns, social distancing, and other measures to contain the pandemic, are felt to some extent across much of the socioeconomic strata. This has the potential to push those with privilege to work for reforms that are both in their own interest and benefit others. Closed schools, for example, have sparked conversations about access and affordability of childcare and gender equity in the home and the workplace (Elias and D'Agostino 2020; King et al. 2020). These issues have become prominent to a greater degree than is common following shock events, such as hurricanes or tornadoes, where disruptions to schools and childcare are short-lived and often accompanied by disruptions to work and homelife. Online education has raised conversations about equity that are focused on access to digital technology but have far-reaching implications beyond enduring the pandemic (Beaunoyer et al. 2020). Privileged populations—wealthy, white elites—have discovered that they, too, can be affected by deficiencies or lack of resilience in our educational and childcare systems. If this recognition sparks action, it could lead to educational reforms or universal childcare that would have widespread benefits.

Already we have some glimpses of optimism. Males taking on more responsibility for housework and childcare may help erode gender norms and create more demand for equity in parenting responsibilities (Alon et al. 2020; Blundell et al. 2020; King et al. 2020). Businesses adopting flexible work arrangements to address

COVID-19 may develop enduring flexible work arrangements that could help employees find work-life balance (Alon et al. 2020; Spurk and Straub 2020) and even lead to transportation reform and a re-design of workspaces (Hensher 2020). Teleconferences, distance presentations, and no-fly decisions have become norms for business meetings and academic conferences (Price 2020; Viglione 2020). An informal poll by Nature found that 80% of academics supported virtual meetings after the pandemic (Woolston 2020), which could benefit not only the environment (through reduced emissions) but also academics from institutions with few resources to pay for travel or academics with child or eldercare responsibilities.

Privileged populations may even be inspired to support reforms to reduce exposure or sensitivity of vulnerable groups, in hopes of reducing the overall severity of the pandemic or lessening harsh government responses. For example, in Victoria, Australia, an outbreak of COVID-19 in a local Afghani community affects the ability of the entire region to lessen strict lockdown protocols. The outbreak has been attributed to high-risk workplaces, reliance on public transportation, and difficulty in spreading health messages in appropriate languages (Mannix and Eddie 2020). The entire state population has a self-interested motive to work for structural reforms to address these root causes: if they want a lighter lockdown, they need to ensure that every community within their state achieves lower case rates. Whether or not this will result in structural shifts remains to be seen, but the connection between personal incentives and collective action creates potential.

We hesitate to paint too rosy a picture. Pandemics have failed before now to inspire policy change (Quinn et al. 2011; Meen et al. 2016), and it is not clear whether any of the benefits we mention will be realized, whether they will be realized before the pandemic ends and public support withers, whether changes will be lasting, or whether lessons learned from COVID-19 will translate to other hazards and aspects of society. It is entirely possible that, rather than push for systemic reforms, wealthy or powerful populations will use their affluence and positions to find solutions not available to other portions of society. They may relocate from urban centers to rural towns to avoid exposure (e.g., Tully and Stowe 2020), hire nannies and private tutors to assist with childcare and homeschooling burdens (e.g., Berman 2020; Rogers 2020), or pay for private schools that offer in-person education rather than work towards fair and effective online education (e.g., Miller 2020). They may even stop donating to social causes, as their own resources dwindle (e.g., Kulish 2020), or avoid policy change due to uncertainty about the future (Mudditt 2020).

21.5 A Broadening Concept of Community Resilience

COVID-19 may or may not inspire broad societal change, but it should change the way we conceive of community resilience. To start, it raises the question: "How much do the healthiest people in society owe to the most vulnerable?" (Mimbs Nyce 2020), or, to phrase it more generally: how much do the most privileged owe the least? Disasters often aggravate wealth inequality in part because the wealthy are able to leverage resources to minimize harms and take advantage of opportunities in ways low-income households are not (Howell and Elliott 2018). Wealthy residents can pay expensive insurance premiums; afford hazard mitigation measures; stay in hotels, rent cars, or use company vehicles when their own are destroyed; or have savings accounts they can draw upon to cover expenses while out of work (Hersher and Benincasa 2019). Wealthy residents can even afford private fire companies to provide additional protection against wildfires (Varian 2019). Whether they should be allowed to purchase additional protection, and whether this is an admission that government-provided protection is insufficient, is an ethical question unanswered to date. Nor is it unique to disasters. Debates have raged for years about whether parents who put their children in private or charter schools reduce the resources available to public education and widen the inequalities between them and families for whom private education is not a choice (see, e.g., Mann and Baker 2018).

This creates potential for privileged and powerful members of society to return to or maintain pre-disaster conditions with relative speed and ease. Transformation of a system to a new stable state requires energy (Holling 1973): in social terms, it requires political, social, and financial capital. If wealthy and powerful members of a system do not act, the system is far less likely to change.

This, then, requires that we re-frame concepts of resilience to answer not only 'of what to what' (Carpenter et al. 2001) but also 'for whom' (Keenan and Hauer 2020). For the individual or the society? For all members of society or for some measure of the collective? Nations may respond to COVID-19 with relatively few changes in their underlying social fabric, thereby demonstrating resilience. However, individuals within those same nations may suffer terribly, and their lives be irrevocably harmed, demonstrating a lack of resilience. In some cases, as described above, the very resilience of the social system may be a cause of the individual's harm. We cannot, then, describe the resilience of the system without making an implicit or explicit statement about resilience for whom. Defining the system, and thereby answering the question 'of what' could include specifying the populations in question, but in pursuit of equitable outcomes associated with public investments in community resilience, it seems important to explicitly draw out this implication, lest it become overwhelmed by system traits.

Similarly, when defining the threat against which the system is to be resilient, the threat may be defined narrowly as a response to a specific threat or broadly as a general ability to deal with uncertainty and stress (Walker and Westley 2011; Carpenter et al. 2012; Lemos et al. 2013). The experiences of COVID-19 argue for a broad conceptualization of general resilience in the case of pandemics and to measure resilience to pandemics not only in terms of public health or economic welfare but other aspects of social well-being that are seemingly-unrelated but have a strong relationship to vulnerability and resilience: issues such as childcare, mental health, domestic abuse, and public transportation. Matin et al. (2018) argue equitable resilience "requires starting from people's own perception of their position within their human-environmental system, and it accounts for their realities and for their need for a change of circumstance.” Accounting for the lived realities of people during the COVID-19 pandemic requires social support systems—food banks, daycares, hotlines, buses—to be placed not at the periphery but at the core of the discussion.

The concept of ‘community resilience’ places emphasis on system-wide metrics of the ‘community’, but in so doing, it may lose focus on the experience of individuals. It may focus our attention on general resilience of the collective at the expense of specific resilience of certain populations within the community who face specific threats not recognized at the community level. When we ask ‘resilience for whom’—what portions of the community—we focus on more tangible experiences, inequities, and potential solutions. At the same time, however, there is a risk in subdividing resilience investments and policies too narrowly, as many social systems interact. Community resilience, then, requires a careful balance to promote equity and specific as well as general resilience.

Ultimately, although the social justice concerns raised by COVID-19 are not novel, the global and long-term nature of the pandemic may inspire a change in how resilience is defined and in how society views the goals of resilience: whether to preserve structures or support individuals. Whether people will rise to the challenge or return to pre-COVID inequities, remains to be seen.

References

Akintobi TH et al (2020) Community engagement of African Americans in the Era of COVID-19: Considerations, challenges, implications, and recommendations for public health. Prev Chronic Dis Centers for Disease Control and Prevention (CDC). https://doi.org/10.5888/PCD17.200255

Akiyama MJ, Spaulding AC, Rich JD (2020) Flattening the curve for incarcerated populations—Covid-19 in jails and prisons. N Engl J Med (Massachussetts Medical Society), 2075–2077. https://doi.org/10.1056/NEJMp2005687

Aldunce P et al (2015) Resilience for disaster risk management in a changing climate: practitioners’ frames and practices. Glob Environ Chang (Elsevier Ltd) 30:1–11. https://doi.org/10.1016/j.gloenvcha.2014.10.010

Alexander DE (2013) Resilience and disaster risk reduction: an etymological journey. Nat Hazards Earth Syst Sci 13(11):2707–2716. https://doi.org/10.5194/nhess-13-2707-2013

Alon TM et al (2020) The impact of COVID-19 on gender equality. Natl Bur Econ Res, 26947. https://doi.org/10.1017/CBO9781107415324.004

Barker M, Russell J (2020) Feeding the food insecure in Britain: learning from the 2020 COVID-19 crisis. Food Secur (Springer) 12(4):865–870. https://doi.org/10.1007/s12571-020-01080-5

Beaunoyer E, Dupéré S, Guitton MJ (2020) COVID-19 and digital inequalities: Reciprocal impacts and mitigation strategies. Comput Hum Behav (Elsevier Ltd) 111:106424. https://doi.org/10.1016/j.chb.2020.106424

Beck AF et al (2016) Explaining racial disparities in child asthma readmission using a causal inference approach. JAMA Pediatr (American Medical Association) 170(7):695–703. https://doi.org/10.1001/jamapediatrics.2016.0269

Berchick ER, Barnett JC, Upton RD (2019) Health insurance Coverage in the United States: 2018 current population reports

Berman J (2020) From nanny services to "private educators," wealthy parents are paying up to $100 an hour for "teaching pods" during the pandemic—MarketWatch. MarketWatch, 23 July. https://www.marketwatch.com/story/affluent-parents-are-setting-up-their-own-schools-as-remote-learning-continues-its-the-failure-of-our-institutions-to-adequately-provide-for-our-students-11595450980. Accessed 24 Sept 2020.

Blandford ED, Sagan SD (eds) (2016) Learning from a disaster: improving nuclear safety and security after Fukushima. Stanford University Press. https://www.sup.org/books/title/?id=24812. Accessed 21 Sept 2020

Blendon RJ et al (2008) Public response to community mitigation measures for pandemic influenza. Emerg Infect Dis (Centers for Disease Control and Prevention, CDC), 778–786. https://doi.org/10.3201/eid1405.071437

Blumenshine P, et al (2008) Pandemic influenza planning in the United States from a health disparities perspective. Emerg Infect Dis (Centers for Disease Control and Prevention, CDC), 709–715. https://doi.org/10.3201/eid1405.071301.

Blundell R et al (2020) COVID-19 and inequalities. Fisc Stud. Blackwell Publishing Ltd 41 (2):291–319. https://doi.org/10.1111/1475-5890.12232

Bovbjerg RR, Hadley J (2007) Why health insurance is important. DC-SPG no. 1. https://www.iom.edu/CMS/3809/. Accessed 24 Sept 2020

Bradbury-Jones C, Isham L (2020) The pandemic paradox: the consequences of COVID-19 on domestic violence. J Clin Nurs (Blackwell Publishing Ltd), 2047–2049. https://doi.org/10.1111/jocn.15296

Bragg C et al (2018) Remittances as aid following major sudden-onset natural disasters. Disasters. Blackwell Publishing Ltd 42(1):3–18. https://doi.org/10.1111/disa.12229

Bremmer I (2020) The best global responses to COVID-19 pandemic. Time, 12 June. https://time.com/5851633/best-global-responses-covid-19/. Accessed 24 Sept 2020

Carpenter SR et al (2001) From metaphor to measurement: Resilience of what to what? Ecosystems 4(8):765–781. https://doi.org/10.1007/s10021-001-0045-9

Carpenter SR et al (2012) General resilience to cope with extreme events. Sustainability 4 (12):3248–3259. https://doi.org/10.3390/su4123248

Clark HM (2017) *Who rides public transportation: Passenger demographics and travel*. https://www.apta.com/wp-content/uploads/Resources/resources/reportsandpublications/Documents/APTA-Who-Rides-Public-Transportation-2017.pdf. Accessed 18 Sept 2020

Clark E et al (2020) Disproportionate impact of the COVID-19 pandemic on immigrant communities in the United States. PLOS Negl Trop Dis. Edited by V. J. Brookes. Public Library Sci 14(7):e0008484. https://doi.org/10.1371/journal.pntd.0008484

Cooper JAG, McKenna J (2008) Social justice in coastal erosion management: The temporal and spatial dimensions. Geoforum 39(1):294–306. https://doi.org/10.1016/j.geoforum.2007.06.007

Crenshaw K (1991) Mapping the margins: Intersectionality, identity politics, and violence against women of color. Stanf Law Rev (JSTOR) 43(6):1241. https://doi.org/10.2307/1229039

Del Boca D et al (2020) Women's and men's work, housework and childcare, before and during COVID-19. Rev Econ Househ (Springer), 1–17. https://doi.org/10.1007/s11150-020-09502-1

Douglas GCC (2015) Conveniently located disaster : socio—spatial Inequality in hurricane sandy and its implications for the urban sociology of climate change

Druss BG (2020) Addressing the COVID-19 pandemic in populations with serious mental illness. JAMA Psychiatry (Journal of the American Medical Association) 77(9):891–892. https://doi.org/10.1001/jama.2020.3413

Elias NM, D'Agostino MJ (2020) Care in crisis: COVID-19 as a catalyst for universal child care in the United States. Adm Theory Prax (Routledge). https://doi.org/10.1080/10841806.2020.1813456

Farré L et al (2020) How the COVID-19 lockdown affected gender inequality in paid and unpaid work in Spain. www.iza.org. Accessed 18 Sept 2020

Folke C et al (2005) Adaptive governance of social-ecological systems. Annu Rev Environ Resour 30(1):441–473. https://doi.org/10.1146/annurev.energy.30.050504.144511

Forde AT et al (2019) The weathering hypothesis as an explanation for racial disparities in health: a systematic review. Ann Epidemiol (Elsevier Inc.), 1–18.e3. https://doi.org/10.1016/j.annepidem.2019.02.011
Fugate C (2011) Five years later: an assessment of the post Katrina Emergency Management Reform Act. In: House committee on homeland security, subcommittee on emergency preparedness, response, and communications. Washington, DC, USA. https://www.fema.gov/pdf/about/programs/legislative/testimony/2011/10_25_2011_five_years_later_assessment_of_pkemra.pdf
Fuller T (2020) Covid limits California's efforts to fight wildfires with prison labor. New York Times 22 August. https://www.nytimes.com/2020/08/22/us/california-wildfires-prisoners.html. Accessed 18 Sept 2020
Gaillard JC, Navizet F (2012) Prisons, prisoners and disaster. Int J Disaster Risk Reduct (Elsevier Ltd) 1(1):33–43. https://doi.org/10.1016/j.ijdrr.2012.05.001
Gearhart S et al (2018) The impact of natural disasters on domestic violence: an analysis of reports of simple assault in Florida (1999–2007). Violence Gend (Mary Ann Liebert Inc.) 5(2):87–92. https://doi.org/10.1089/vio.2017.0077
Gibney E (2020) Whose coronavirus strategy worked best? Scientists hunt most effective policies. Nature NLM (Medline), 15–16. https://doi.org/10.1038/d41586-020-01248-1
Gold MS et al (2020) COVID-19 and comorbidities: a systematic review and meta-analysis. Postgrad Med. Taylor and Francis Inc., 1–7. https://doi.org/10.1080/00325481.2020.1786964
Goodkind N (2020) California is facing a wildfire fighter shortage because prisoners are getting sick with COVID. Fortune, 15 July. https://fortune.com/2020/07/15/california-wildfires-firefighters-prisoners-inmates-covid-coronavirus/. Accessed 18 Sept 2020
Gunnell D et al (2020) Suicide risk and prevention during the COVID-19 pandemic. The Lancet Psychiatry 7(6):468–471. https://doi.org/10.1016/S2215-0366(20)30171-1
Hayward BM (2013) Rethinking resilience: Reflections on the earthquakes in Christchurch, New Zealand, 2010 and 2011. Ecol Soc (The Resilience Alliance) 18(4). https://doi.org/10.5751/ES-05947-180437
Hensher DA (2020) What might Covid-19 mean for mobility as a service (MaaS)? Transp Rev (Routledge) 40(5):551–556. https://doi.org/10.1080/01441647.2020.1770487
Hersher R, Benincasa R (2019) How federal disaster money favors the rich. National Public Radio, 5 March. https://www.npr.org/2019/03/05/688786177/how-federal-disaster-money-favors-the-rich. Accessed 24 Sept 2020
Holling CS (1973) Resilience and stability of ecological systems. Annu Rev Ecol Syst 4:1–23. www.annualreviews.org. Accessed 18 Sept 2020
Hosseini S, Barker K, Ramirez-Marquez JE (2016) A review of definitions and measures of system resilience. Reliab Eng Syst Saf (Elsevier Ltd) 145:47–61. https://doi.org/10.1016/j.ress.2015.08.006
Howell J, Elliott JR (2018) Damages done: the longitudinal impacts of natural hazards on wealth inequality in the United States. Soc Probl 412:1–20. https://doi.org/10.1093/socpro/spy016
HUD (2020) Annual homeless assessment report to congress. Washington, DC, USA. https://www.hudexchange.info/resource/5948/2019-ahar-part-1-pit-estimates-of-homelessness-in-the-us/. Accessed 24 Sept 2020
Jerneck A, Olsson L (2008) Adaptation and the poor: development, resilience and transition. Clim Policy (Taylor & Francis Group) 8(2):170–182. https://doi.org/10.3763/cpol.2007.0434
Kang SJ, Jung SI (2020) Age related morbidity and mortality among patients with COVID-19. Infect Chemother (Korean Society of Infectious Diseases) 52(2):154. https://doi.org/10.3947/ic.2020.52.2.154
Keenan JM (2018) Types and forms of resilience in local planning in the US: Who does what? Environ Sci Policy (Cambridge, MA, USA) 88:116–123
Keenan JM, Hauer ME (2020) Resilience for whom? Demographic change and the redevelopment of the built environment in Puerto Rico. Environ Res Lett 15(7):074028. https://doi.org/10.1088/1748-9326/ab92c2

King T et al (2020) Reordering gender systems: can COVID-19 lead to improved gender equality and health? The Lancet 396:80–81. https://doi.org/10.1016/S0140-6736(20)31418-5
Klein RJT, Nicholls RJ, Thomalla F (2003) Resilience to natural hazards: How useful is this concept? Environ Hazards 5(1–2):35–45. https://doi.org/10.1016/j.hazards.2004.02.001
Kulish N (2020) Food banks are overrun, as coronavirus surges demand. The New York Times, 6 May. https://www.nytimes.com/2020/04/08/business/economy/coronavirus-food-banks.html. Accessed 24 Sept 2020
Kullar R et al (2020) Racial disparity of coronavirus disease 2019 in African American communities. J Infect Dis. NLM (Medline) 222(6):890–893. https://doi.org/10.1093/infdis/jiaa372
Lancet (2020) The plight of essential workers during the COVID-19 pandemic. The Lancet 395:1587. https://doi.org/10.1007/s00134-020-05991-x.Bizzarro
Langellier BA (2020) Policy recommendations to address high risk of COVID-19 among immigrants. Am J Public Health 110(8):1137–1139. https://doi.org/10.2105/AJPH.2020.305792
Le Dé L, Gaillard JC (2017) Disaster risk reduction and emergency management in prison: a scoping study from New Zealand. J Contingencies Cris Manag (Blackwell Publishing Ltd), 376–381. https://doi.org/10.1111/1468-5973.12165
Lemos MC et al (2013) Building adaptive capacity to climate change in less developed countries. In: Asrar GR, Hurrell JW (eds) Climate science for serving society: research, modeling and prediction priorities. Springer Science+Business Media, Dordrecht, pp 437–457
Lima NNR et al (2020) People experiencing homelessness: their potential exposure to COVID-19. Psychiatry Res (Elsevier Ireland Ltd), 112945. https://doi.org/10.1016/j.psychres.2020.112945
MacKinnon D, Derickson KD (2013) From resilience to resourcefulness: a critique of resilience policy and activism. Prog Hum Geogr 37(2):253–270. https://doi.org/10.1177/0309132512454775
Mann B, Baker DP (2018) Cyber charter schools and growing resource inequality among public districts: Geospatial patterns and consequences of a statewide choice policy in Pennsylvania, 2002–2014. Am J Educ 125:147–171
Mannix L, Eddie R (2020) New COVID-19 hotspot emerges in Melbourne's south-east. The Age, 14 September. https://www.theage.com.au/national/victoria/new-covid-19-hotspot-emerges-in-melbourne-s-south-east-20200914-p55vj1.html
MAPC (2020) The COVID-19 layoff housing gap. Boston, MA, USA. https://www.mapc.org/resource-library/covid-19-layoffs-october/
Matin N, Forrester J, Ensor J (2018) What is equitable resilience? World Dev (The Authors) 109:197–205. https://doi.org/10.1016/j.worlddev.2018.04.020
McCormack G et al (2020) Economic vulnerability of households with essential workers. J Am Med Assoc 324(4):388–390. https://doi.org/10.1001/jama.2020.11366
Meen G et al (2016) Wars, epidemics and early housing policy: The long-run effects of temporary disturbances. In: Housing economics: a historical approach. Palgrave Macmillan UK, London, 111–135. https://doi.org/10.1057/978-1-137-47271-7_5
Mein SA (2020) COVID-19 and health disparities: the reality of "the great equalizer." J Gen Intern Med (Springer) 35(8):2439–2440. https://doi.org/10.1007/s11606-020-05880-5
Metzl J, Maybank A, De Maio F (2020) Responding to the COVID-19 pandemic: The need for a structurally competent health care system. JAMA - J Am Med Assoc 324(3):231–232
Miller CC (2020) In the same towns, private schools are reopening while public schools are not. The New York Times, 3 August. https://www.nytimes.com/2020/07/16/upshot/coronavirus-school-reopening-private-public-gap.html. Accessed 24 Sept 2020
Mimbs Nyce C (2020) One virus, two Americas. The Atlantic, 30 March. https://www.theatlantic.com/newsletters/archive/2020/03/one-virus-two-americas/609148/. Accessed 18 Sept 2020
Monk EP (2019) The color of punishment: African Americans, skin tone, and the criminal justice system. Ethn Racial Stud (Taylor & Francis) 42(10):1593–1612. https://doi.org/10.1080/01419870.2018.1508736
Mudditt J (2020) How offices will change after coronavirus. BBC, 14 May. https://www.bbc.com/worklife/article/20200514-how-the-post-pandemic-office-will-change. Accessed 18 Sept 2020

O'Donovan K (2017) An assessment of aggregate focusing events, disaster experience, and policy change. Risk, Hazards Cris Public Policy (Wiley-Blackwell Publishing Ltd) 8(3):201–219. https://doi.org/10.1002/rhc3.12116

OSHA (2009) Healthcare workplaces classified as very high or high exposure risk for pandemic influenza. Occupational Safety & Health Administration, US Department of Labor. https://www.osha.gov/Publications/exposure-risk-classification-factsheet.html. Accessed 24 Sept 2020

Petretto DR, Masala I, Masala C (2020) Special educational needs, distance learning, inclusion and COVID-19. Educ Sci 10(6):1–2. https://doi.org/10.3390/educsci10060154

Porter K (2020) City prepares for a flood season without volunteers. Canadian Broadcasting Company, 8 April. https://www.cbc.ca/news/canada/ottawa/sandbags-preparation-flooding-no-volunteers-1.5525544. Accessed 24 Sept 2020

Poteat T et al (2020) Understanding COVID-19 risks and vulnerabilities among black communities in America: the lethal force of syndemics. Ann Epidemiol (Elsevier Inc.) 47:1–3. https://doi.org/10.1016/j.annepidem.2020.05.004

Price M (2020) As COVID-19 forces conferences online, scientists discover upsides of virtual format. Science (American Association for the Advancement of Science, AAAS). https://doi.org/10.1126/science.caredit.abc5170

Purdum JC, Meyer MA (2020) Prisoner labor throughout the life cycle of disasters. Risk, Hazards Cris Public Policy (Wiley-Blackwell Publishing Ltd) 11(3):rhc3.12191. https://doi.org/10.1002/rhc3.12191

Quinn SC et al (2011) Racial disparities in exposure, susceptibility, and access to health care in the US H1N1 influenza pandemic. American J Public Health (American Public Health Association) 101(2):285–293. https://doi.org/10.2105/AJPH.2009.188029

Raisi-Estabragh Z et al (2020) Greater risk of severe COVID-19 in Black, Asian and Minority Ethnic populations is not explained by cardiometabolic, socioeconomic or behavioural factors, or by 25(OH)-vitamin D status: study of 1326 cases from the UK Biobank. J Public Health 42 (3):451–460. https://doi.org/10.1093/pubmed/fdaa095

Reese B (2020) Putnam County lacks tornado cleanup volunteers amid COVID-19. WKRN News, 15 April. https://www.wkrn.com/news/local-news/putnam-county-lacks-volunteers-for-tornado-cleanup-amid-covid-19/. Accessed 24 Sept 2020

Rogers TN et al (2020) Racial disparities in COVID-19 mortality among essential workers in the United States. World Med Health Policy (Blackwell Publishing Ltd) 12(3):wmh3.358. https://doi.org/10.1002/wmh3.358

Rogers TN (2020) Coronavirus school shutdowns: wealthy parents hire private educators. Business Insider, 27 May. https://www.businessinsider.com/coronavirus-school-shutdowns-wealthy-parents-hire-private-educators-2020-5. Accessed 24 Sept 2020

Saloner B et al (2020) COVID-19 cases and deaths in federal and state prisons. JAMA - J Am Med Assoc, 602–603. https://doi.org/10.1001/jama.2020.12528

Schumacher JA et al (2010) Intimate partner violence and Hurricane Katrina: Predictors and associated mental health outcomes. Violence Vict (Springer Publishing Company) 25(5):588–603. https://doi.org/10.1891/0886-6708.25.5.588

UNDRR (2015) Sendai framework for action on disaster risk reduction for 2015–2030. United Nations International Strategy for Disaster Reduction, A/Conf. 224/CRP. 1, 18 March 2015

Siders AR (2016) Resilience incoherence—seeking common language for climate change adaptation, disaster risk reduction, and sustainable development. In: Peel J, Fisher D (eds) The role of international environmental law in disaster risk reduction. Brill Nijhoff, Leiden and Boston, pp 101–127. https://doi.org/10.1163/9789004318816

Siders AR (2018) Social justice implications of US managed retreat buyout programs. Clim Change 152(2):239–257. https://doi.org/10.1007/s10584-018-2272-5

Spurk D, Straub C (2020) Flexible employment relationships and careers in times of the COVID-19 pandemic. J Vocat Behav 119:103435. https://doi.org/10.1016/j.jvb.2020.103435

Thomas NM (2006) What's missing from the weathering hypothesis? Am J Public Health (American Public Health Association) 96(6):955.https://doi.org/10.2105/AJPH.2006.085514

Tierney K (2006) Social inequality, hazards, and disasters. In: Daniels RJ, Kettl DF, Kunreuther H (eds) On risk and disaster: lessons from Hurricane Katrina. University of Pennsylvania Press, Philadelphia, PA, USA

Timothy RK (2020) Coronavirus is not the great equalizer—race matters. The Conversation, 6 April. https://theconversation.com/coronavirus-is-not-the-great-equalizer-race-matters-133867. Accessed 18 Sept 2020

Tinubu Ali T, Herrera M (2020) Distance learning during COVID-19: Seven equity considerations for schools and districts. South Educ Found (April):1–6. https://files.eric.ed.gov/fulltext/ED605744.pdf

Tobolowsky FA et al (2020) COVID-19 outbreak among three affiliated homeless service sites—King County, Washington, 2020, MMWR. Morbidity and Mortality Weekly Report. Cent Dis Control MMWR Off 69(17):523–526. https://doi.org/10.15585/mmwr.mm6917e2

Tully T, Stowe S (2020) The wealthy flee Coronavirus. Vacation towns respond: Stay away. The New York Times, 25 March. https://www.nytimes.com/2020/03/25/nyregion/coronavirus-leaving-nyc-vacation-homes.html?login=email&auth=login-email&login=email&auth=login-email. Accessed 24 Sept 2020

Ulibarri N, Scott TA (2019) Environmental hazards, rigid institutions, and transformative change: How drought affects the consideration of water and climate impacts in infrastructure management. Glob Environ Change 59(February):102005. https://doi.org/10.1016/j.gloenvcha.2019.102005

UNDRR (2009) 2009 UNISDR terminology on disaster risk reduction. https://reliefweb.int/report/world/2009-unisdr-terminology-disaster-risk-reduction. Accessed 21 Sept 2020

United Nations (2020) Policy Brief: the impact of COVID-19 on women. https://www.un.org/development/desa/dpad/. Accessed 18 Sept 2020

Usher K et al (2020) Family violence and COVID-19: Increased vulnerability and reduced options for support. Int J Ment Health Nurs. Blackwell Publishing, 549–552. https://doi.org/10.1111/inm.12735

Van Lancker W, Parolin Z (2020) COVID-19, school closures, and child poverty: a social crisis in the making. The Lancet Public Health. The Author(s). Published by Elsevier Ltd. This is an Open Access article under the CC BY 4.0 license 5(5):e243–e244. https://doi.org/10.1016/S2468-2667(20)30084-0

Varian E (2019) While California fires rage, the rich hire private firefighters. The New York Times, 26 October. https://www.nytimes.com/2019/10/26/style/private-firefighters-california.html. Accessed 24 Sept 2020

Viglione G (2020) How scientific conferences will survive the coronavirus shock. Nature. NLM (Medline) 582(7811):166–167. https://doi.org/10.1038/d41586-020-01521-3

Walker J, Cooper M (2011) Genealogies of resilience: From systems ecology to the political economy of crisis adaptation. Security Dialogue 42(2):143–160. https://doi.org/10.1177/0967010611399616

Walker B, Westley F (2011) Perspectives on resilience to disasters across sectors and cultures. Ecol Soc 16(2):0–4. https://doi.org/10.5751/ES-04070-160204

WHO (2005) Is violence a problem after disasters? Geneva, Switzerland. www.who.int/violence_injury_prevention/violence/world_report. Accessed 18 Sept 2020

Woolston C (2020) Learning to love virtual conferences in the coronavirus era. Nature (Nature Research), 135–136. https://doi.org/10.1038/d41586-020-01489-0

Yang J et al (2020) Prevalence of comorbidities and its effects in coronavirus disease 2019 patients: a systematic review and meta-analysis. Int J Infect Dis (Elsevier B.V.) 94:91–95. https://doi.org/10.1016/j.ijid.2020.03.017

Chapter 22
The Vaccine Supply Chain: A Call for Resilience Analytics to Support COVID-19 Vaccine Production and Distribution

Maureen S. Golan, Benjamin D. Trump, Jeffrey C. Cegan, and Igor Linkov

Abstract Pharmaceutical companies, upstream suppliers, associated logistics providers, health workers, regulatory agencies, public health experts and ultimately the medical practitioners and general public have been navigating an increasingly globalized vaccine supply chain; any disruption to the supply chain may cause cascading failure and have devastating consequences. The COVID-19 pandemic has already highlighted the lack of resilience in supply chains, as global networks fail from disruptions at single nodes and connections. As the race for a COVID-19 vaccine continues, the importance of not only an efficient supply chain but a resilient vaccine supply chain capable of reliable production and reaching target populations despite likely but currently unknown disruptions is imperative. Proactively applying resilience analytics to vaccine supply chain models will increase the probability that vaccination programs meet their goals. Without such a network in place for manufacture and distribution of the COVID-19 vaccine, even the most efficacious and safe vaccine will not prove viable. Through an overview of the existing vaccine and pharmaceutical supply chain publications focusing on resilience, as well as recent papers reporting modeling of resilience in supply chains across multiple fields, we find that models for supply chain resilience are few and most of them are focused on individual dimensions of resilience rather than on comprehensive strategy necessary for scaling up vaccine production and distribution in emergency settings. We find that COVID-19 resulted in a wave of interest to supply chain resilience, but publications from 2020 are narrow in focus and largely qualitative in nature; evidence-based models and measures are rare. Further, publications often focus exclusively on specific portions of the specific supply chain of interest, excluding associated supporting networks, such as transportation, social and command and control (C2) necessary for vaccine production and equitable

M. S. Golan (✉) · B. D. Trump · J. C. Cegan · I. Linkov
US Army Engineer Research and Development Center, Vicksburg, USA
e-mail: maureengolan@gmail.com

I. Linkov
e-mail: Igor.Linkov@usace.army.mil

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8_22

distribution. This lack of network analysis is a major gap in the literature that needs to be bridged in order to create methods of real-time analysis and decision tools for the COVID-19 vaccine supply chain. We conclude that a comprehensive, quantitative approach to network resilience that encompasses the supply chain in the context of other social and physical networks is needed in order to address the emerging challenges of a large-scale COVID-19 vaccination program. We further find that the COVID-19 pandemic underscores the necessity of positioning supply chain resilience within a multi-network context and formally incorporating temporal dimensions into analysis through the NAS definition of resilience—plan, absorb, recover, adapt—to ensure essential needs are met across all dimensions of society. Modeling and analyzing vaccine supply chain resilience ensures that value is maintained should disruptions occur.

Keywords Vaccine supply chain resilience · Supply chain resilience · Vaccine supply chain · Pharmaceutical supply chain · COVID-19 supply chain

22.1 Introduction

Even in the earliest days of the novel coronavirus SARS-CoV-2 pandemic, considerable public and academic attention has been paid upon the development and distribution of a vaccine that can safely and effectively inoculate the global population. In the absence of other successful preventative measures, public health scholars and policymakers around the world have emphasized this goal is one of achieving "herd immunity," whereby SARS-CoV-2 would not easily be able to spread within a given population given its fundamental biological characteristics and natural reproduction rate. In turn, a critical rate-limiting step to reaching this end goal includes the vast and complex supply chain network underpinning the production and distribution of any vaccine candidate. In this chapter, we review various discourse and challenges related to the robustness and resiliency of pharmaceutical supply chain networks, and note where potential single-points-of-failure may arise that may substantially degrade or even destroy supply chain capacity for successful vaccine development and delivery. In this, we argue that for those points of concern that may jeopardize the sources of any critical vaccine effort, the capacity for system recovery and adaptation must be fostered regardless of the disruption that may be faced in the near or extended future.

As of the beginning of October 2020 there have been more than 34 million cases of COVID-19 (the illness caused by SARS-CoV-2) worldwide with total documented deaths having exceeded one million at the end of September 2020 (WHO 2020b). Complicating the pandemic, co-disruptions such as political unrest and evacuations due to the 2020 storm season decrease the potential to mitigate waves of illness outbreak (Rowland et al. 2020). As cases, death tolls, and socioeconomic consequences rise, finding a viable vaccine is increasingly urgent. As of October 19, 2020, there were 44 candidate vaccines for the novel coronavirus SARS-CoV-2, ranging in approach, from the developer/manufacturer to type of vaccine, number of doses, timing of the doses and route of administration (WHO 2020a). The number of variables in vaccine development add clear complications for planning a large-scale immunization campaign, especially because all but two of the top ten candidate vaccines in Phase III clinical trials as of October 2020 are designed as two-dose vaccines (WHO 2020b). A two-dose vaccine will increase the burden on the vaccine supply chain, further necessitating the need for a resilient network to be in place and ready to plan, absorb, recover, and adapt to disruptions.

The COVID-19 pandemic highlights the need for building resilient supply chains. In the case of the pandemic, supply chains have been disrupted from all angles. The pandemic caused not a singular disruption, but cascading disruptions affecting multiple nodes, links, and associated networks, including an impact on the demand for certain goods and services. The global nature of supply networks and the movement of goods, information and services has caused unanticipated disruptions for supply chain managers and government agencies. For example, we can look to the global repercussions of China's actions during the onset of the COVID-19 pandemic. The U.S.-China Economic and Security Review Commission found that the stringent restrictions on movement and labor shortages in China caused a sudden drop in China's oil imports, which affected the OPEC supply chain, and caused a disruption to transportation and shipping (Malden and Stephens 2020). This disruption was estimated to affect 75% of U.S. companies, especially impacting electronics, pharmaceuticals, and automotive industry supply chains (Malden and Stephens 2020). An over-reliance on China for electronics manufacturing is a factor cited by DHL's Resilience360 as one of its ten key risks facing global tech supply chains, and ultimately recommend re-evaluating supplier and distribution networks post-COVID-19 (DHL 2020). Similarly, the United States medical and pharmaceutical supply chain is heavily dependent on Chinese manufacturing with a large share of medical and laboratory apparel imported from China (Schwarzenberg and Sutter 2020). Although many of the higher value added products such as biological products and vaccines come from imports (79%), less than 0.05% come from China, with 59% from the European Union under normal circumstances, highlighting the effects that foreign policy as well as dynamics within other countries may have on global supply chains (Elton et al. 2020; Schwarzenberg and Sutter 2020; Sutter et al. 2020).

Echoing this conclusion, a survey of supply chain executives within the first months of the pandemic found that 58% of respondents intend to pivot from single sourcing (Hoek 2020). However, as China's early quarantine lockdowns have slowed the spread of the virus, manufacturing output has increased, but demand and consumption continue to lag, leading to questions concerning inventory and warehousing growth (Feng 2020). This demand uncertainty affects supply chain continuity, as corroborated by an analysis of NASDAQ 100 companies' Twitter feeds spanning from January 2020 to April 2020 (Sharma et al. 2020). As supply chains shift to expand their networks, resilience analytics of the necessary co-networks such as transportation, C2 and Industry 4.0 will need to be evaluated and quantified in tandem with the supply chain itself (Golan et al. 2020).

Geographic sector clustering is also a phenomenon that has supply chain implications. Consequently, the magnitude of a disruption's impact on the domestic supply chain network is traditionally related to the location of origin within the country, as seen in the Coronavirus pandemic (Gomez et al. 2020). Gomez et al. use threshold analysis to find that a disruption in the central U.S. to a supply chain node leads to a larger supply chain failure propagated throughout the country, particularly in the agriculture and food sectors (2020). The effects extend across the border to Canada where border politics and quarantine policies further affect the agriculture supply chains built on just-in-time manufacturing and delivery, and over-land transportation (Hobbs 2020). Understanding the implications of supply chain dependencies on other networks, geographic constraints and policy has been highlighted by the COVID-19 pandemic, supporting our finding for enhanced resilience analytics for vaccine supply chains.

Applying "Industry 4.0" to supply chain management—the move towards more "intelligent" processes, smart technologies, machine learning, digitalization, and overall cyber-physical integration of manufacturing and logistics—allows for big data to be processed in useful manners that can be geared and applied towards resilience and hardening weak points on the supply chain (Golan et al. 2020; Ivanov and Dolgui 2020b; Cavalcante et al. 2019). Collaboration among supply chain tiers and open communication in combination with Industry 4.0 tools such as blockchain, digital supply chain twins, and real-time supply chain updates are coming to the forefront in response to current themes in supply chain resilience (Ivanov and Dolgui 2020b; Sharma et al. 2020; Hobbs 2020; Cavalcante et al. 2019). One especially hard-hit supply chain is the Personal Protective Equipment (PPE), which has also had repercussions on other supply chains due to the inability of people to return to work without proper medical protection. Although gaining mainstream attention during the COVID-19 pandemic, prior analysis foreshadowed this inability for the PPE supply chain to meet demand should a large-scale medical emergency arise (Patel et al. 2017). In the United States, for example, meeting glove, gown, and surgical mask demand will require imports, while the N95 mask, face shield, nasal swab and test kit demand can be (or is expected to be) nearly filled by domestic production, despite the rapidly changing supply chain due to demand increase, non-traditional suppliers, and non-traditional PPE industry users (Elton et al. 2020).

One strategy that is helping to fill this medical supply gap is 3-D printing, which disperses the supply chain. This tool can fill time-critical manufacturing shortages and has been used to source nasal swabs, face shields, and respirator and ventilator components (Salmi et al. 2020). For example, the National Institutes of Health (NIH) 3D Print Exchange hosts a specific web portal for the *COVID-19 Supply Chain Response*, which includes a collection of PPE designs for clinical and/or community use (NIH 2020). The decentralized aspect of 3D printing, combined with the expansion of accessible technology and Industry 4.0, as well more efficient, and made-to-order aspects of 3D printing show the importance of this technology in supply chains moving forward (Choong et al. 2020). This trend also underscores the notion of private-public cooperation during times of national and global crisis that promote agility in the supply chain, as seen during the 2009 H1N1 and 2014 Ebola epidemic responses (Patel et al. 2017). The PPE supply chain shows the importance of analyzing all network connections in order to understand supply chains because as demonstrated by the COVID-19 pandemic, a failure in necessary supplies of PPE lead to direct and indirect impacts on other supply chains.

As touched upon previously in the geographic perspective, the agriculture and food industries are another example of a sector which has been forced to shift its supply chain due to the COVID-19 pandemic. As with PPE, farming and agriculture supply chains have been disrupted, and the industry has been unable to equitably and adequately meet the basic needs of people across the globe. The COVID-19 pandemic has cascading impacts that are aggravating hunger, hidden-hunger (i.e. malnutrition), and food waste by disrupting access to fresh and affordable foods (Lal 2020). This is an issue of supply chain resilience. Similar to wide-spread use of 3D printing during the pandemic, a more decentralized food system has been suggested to meet current food needs, through trends such as home gardening and urban agriculture (HGUA), delivery apps, and sourcing from local vendors who are less susceptible to border disruptions and labor shortages (Hobbs 2020; Lal 2020). The examples of food and medical supplies in particular highlight the fact that as supply chains are strained, maintaining equitable distribution of essential goods and services must be addressed and ensured through resilience measures.

This strain from the pandemic can be compared to other global stressors. The 2008 global financial crisis has been exemplified to show that stress tests similar to those imposed on U.S. and E.U. banks in the wake of the global crisis can also be advanced by governments to ensure essential supply chains do not fail (Simchi-Levi and Simchi-Levi 2020). The 2008 financial crisis shows how the field of resilience analytics offers a theoretical foundation for policy making in the face of systemic risks and uncertainties (Hynes et al. 2020b) and can be applied to other complex networks to ensure that critical supplies such as vaccines are available during and immediately after disruptive events. An example of a simple resilience "stress test" is that of Simchi-Levi and Simchi-Levi, which quantifies "time to survive (TSS)" and "time to recover (TRR)," giving a tangible metric for ensuring TSS is greater than TRR (Simchi-Levi and Simchi-Levi 2020). Although overarching regulation might mitigate any cascading failures caused across fragile supply networks, a more complete network model encompassing all "intertwined supply networks (ISN)" is necessary (Ivanov and Dolgui 2020a). This would need to specifically addresses supply chain interdependencies on other networks, as well as trade-offs (e.g. impacts of product cost versus supply continuity) in order to enable true resilience analytics.

The current disruption to existing supply chains due to impacts of the COVID-19 pandemic are evidence of the potential demand for proactive resilience analytics in the COVID-19 vaccine supply chain. A resilient vaccine supply chain will increase the probability of continuous functionality in the face of disruptions, and equitable distribution of the vaccine.

This chapter began by first contextualizing supply chains in general within the systemic threats caused by COVID-19, showing how seemingly unconnected networks have experienced disruptions due to impacts from the pandemic. Next, an overview of the COVID-19 vaccine process is fundamental in understanding the underlying value chain inherent in vaccine production, and the networks that will support resiliency of the system. This section then segues into an overview of the vaccine supply chain and the unique challenges it poses from the manufacturing ecosystem, to the cold chain and the last mile, to reverse logistics and waste management. The existing understanding of the associated networks that enable the vaccine supply chain are also discussed, highlighting the smallpox and MMR vaccination campaigns as case studies, before discussing the existing understanding of disruptions in the vaccine supply chain. Because much of the existing literature and studies on vaccine supply chain is focused on humanitarian response and immunization campaigns, there is a focus on preparing for expected disruptions such as inconsistent power grids in the cold chain. However, unexpected disruptions must also be prepared for as exemplified in the next sections discussing resilience analytics.

The last sections of the chapter transition into a discussion on resilience analytics in supply chain modeling and the clear need for application in the vaccine supply chain. Although the need for modeling resilience in vaccine supply chain is clear, we find a clear lack of focus on this aspect of the vaccine supply chain in existing academic publications, especially in regard to the manufacturing ecosystem. We therefore look at recent trends in modeling supply chain resilience in publications addressing impacts of COVID-19. We then apply these general supply chain modeling trends to the vaccine supply chain and provide recommendations for the COVID-19 vaccine supply chain.

22.2 Vaccine Supply Chains

As the global health toll rises, the COVID-19 vaccine is under accelerated development (WHO 2020b; HHS 2020b). Traditional vaccine development proceeds in a linear manner: (1) pre-clinical studies; (2) phase I clinical trials; (3) phase II clinical trials; (4) phase III clinical trials; (5) infrastructure; (6) manufacturing; (7) approval; (8) distribution and Phase IV post marketing surveillance (WHO 2020b). This linear development allows for reduced risk for stakeholders, infrastructure, and networks associated with the (potential) vaccine as the efficacy and viability of production and clinical studies must be proven before proceeding with each step. However, due to the global nature of the COVID-19 pandemic and the vast toll on human health, the vaccine is under an accelerate development timeline, which overlaps the steps in vaccine development: (1) pre-clinical, phase I, phase II, phase III, infrastructure, manufacturing; (2) approval, distribution; (3) phase IV (WHO 2020b). Applying the notion of value chain, whereby the "value" of a product increases exclusive of initial costs in order to gain competitive advantage

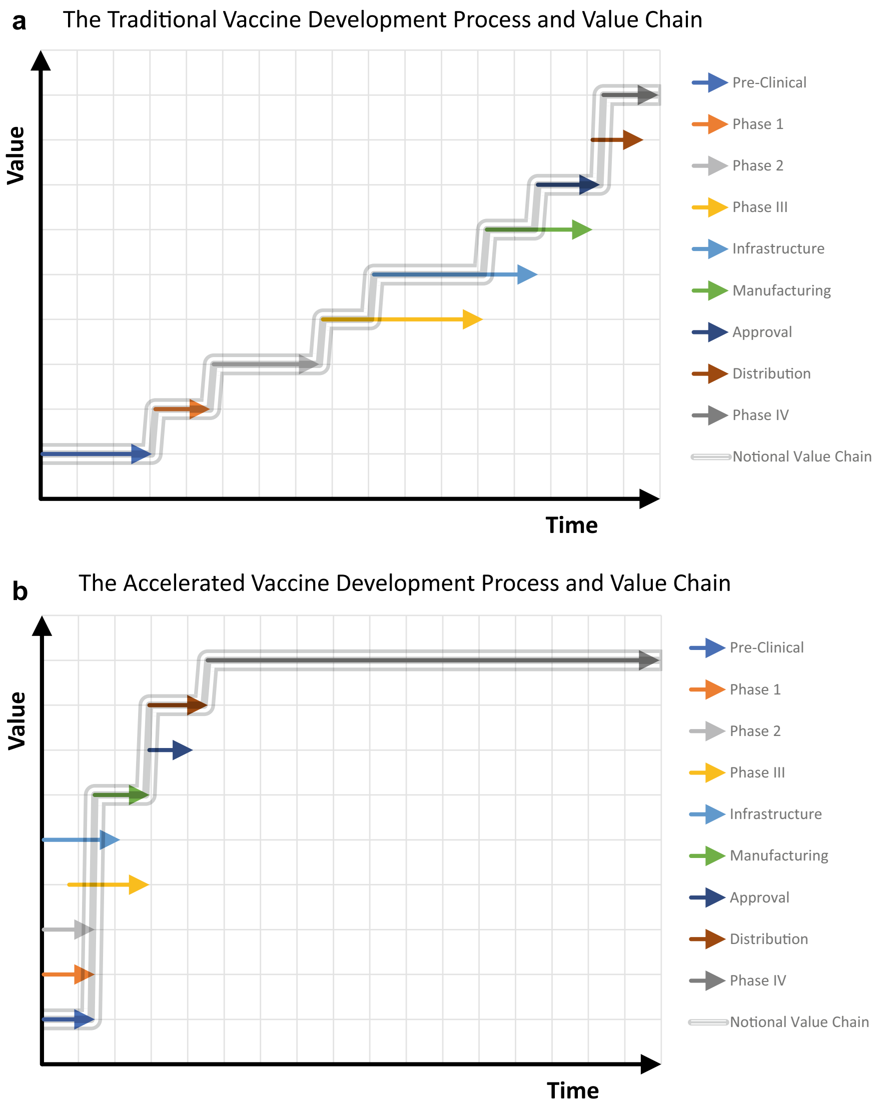

Fig. 22.1 The traditional (**a**) and accelerated (**b**) vaccine development processes in relation to the value chain (see Linkov et al. 2020 for discussion of value chain and resilience)

(Porter 1985), the accelerated vaccine development (Fig. 22.1b) gains value much faster than the traditional vaccine development (Fig. 22.1a). In both cases, in order for a successful vaccine deployment to occur, and to maintain continued optimal performance, resiliency must be built into the system.

This unprecedented acceleration and volume of vaccine required furthers the burden on the supply chain. For this reason, many of the first proposed treatments and vaccine studies looked at existing medicines, such as ribavirin, due to existing inventories and reliable supply chains (Khalili et al. 2017). However, as novel techniques for vaccine manufacture are investigated and implemented in an accelerated process, unprecedented strain and risk will be placed on manufacturing (Graham 2020). Vaccine manufacturing is already more challenging than typical small molecule pharmaceuticals due to the compound risk of physical and biological variability, different populations approved for each vaccine (e.g. pregnant women, infants, immunocompromised persons), level of antibody response, and side effects, leaving many vaccine manufacturers to fail despite the unmet immunization demand (WHO 2020b; Plotkin et al. 2017). Although understood to be a risky business despite protocols enumerated by regulatory and governing agencies, insight into infrastructure and distribution networks beyond the manufacturing process itself—the network of underlying supply chains—that will ultimately be required for the future vaccine must be analyzed. A resilient vaccine supply chain must be implemented to ensure that once a vaccine is ready for Phase IV, populations will be able to access the vaccine in an equitable manner.

The viability and efficacy of a COVID-19 vaccine must be analyzed in tandem with the networks that will create value and support network resilience post disruption. Without an efficient supply chain capable of withstanding disruptions (i.e. resilient), even the most effective vaccine will be rendered ineffective at disease prevention.

22.2.1 Vaccine Supply Chains

In general, pharmaceutical manufacturers depict vaccine production semi-linearly from raw material reception, active ingredient manufacturing, coupling and formulation, filling, packaging and lot release, shipment, and distribution (Sanofi 2019; VE 2016). In broader terms, global immunization programs, such as the GAVI Alliance, which promotes increased access to vaccines in developing countries, underscores the importance of supply chain through promotion of its five pillars: people and practice, cold chain equipment, data for management, distribution and system design (Brownlow and Thornton 2014). In sum, the efficacy of the vaccine depends not only on the supply chain that distributes the final product, but the supply chains underpinning the manufacture itself. The importance of the manufacturing ecosystem is highlighted by the fact that both the specific biological entity and the specific production process are regulated, with even subtle changes to consumables compromising final safety, efficacy and purity, meaning that even if the product remains theoretically identical, if the process changes, clinical trials and licensing will need to occur again (Plotkin et al. 2017). This is highlighted by the fact that many vaccine patents protect the manufacturing process rather than the active antigen produced by that process (Plotkin et al. 2017). Therefore, a steady supply chain of constant and high-quality materials (i.e. consumables) is crucial from the beginning of the vaccine supply chain.

Understanding the entire vaccine supply chain leading to manufacture and from manufacture to the last mile is essential to modeling the entire network, with all its interactions. Therefore, this section, breaks out the vaccine supply chain into *manufacturing*, which addresses the upstream and downstream consumables through secondary packaging (Sect. 22.2.2); *cold chain*, which addresses the distribution challenges of vaccine supply chains (Sect. 22.2.3); *last mile*, which addresses the fundamental goal of the vaccine supply chain: meeting immunization targets (Sect. 22.2.4); *reverse logistics and (biohazard) waste management*, which addresses the additional supply chains nodes and links necessary for disposal of medical waste and returned cold chain equipment (Sect. 22.2.5); and *vaccine supply chains and interconnected networks*, which addresses the network qualities of the vaccine supply chain and its dependence on associated networks such as transportation and command and control (C2) (Sect. 22.2.6).

Similar to the vaccine overview provided, this section is intended as a basis for understanding vaccine supply chain complexities and constraints in relation to the current state of vaccine supply chain models, and areas that need to be addressed for a large-scale pandemic inoculation campaign to maintain optimal performance. Although broken out into sub-sections, there is inherent overlap, and is meant as a tool for highlighting components of the vaccine supply chain.

22.2.2 Manufacturing

The average vaccine manufacturing process takes from 6 to 36 months due to not only the complexity of the biopharmaceuticals themselves, but also the quality control processes, which represent about 70% of the manufacturing duration (Sanofi 2019; VE 2016). The production of each vaccine is unique, but generally includes (1) raw material reception, with some vaccines requiring ~160 unique consumables; (2) bacteria, virus, or cell culture; (3) harvesting; (4) purification; (5) inactivation; (6) valence assembly; (7) formulation; (8) filling; (9) freeze-drying; (10) packaging; (11) batch release (Sanofi 2019; VE 2016). These steps in turn rely on their own raw materials supply chains, such as glassware and pharmaceuticals, as well as platform specific factory capabilities (Rele 2020). Although these processing stages are ultimately monitored for efficacy and human health guidelines through strict licensing requirements, the mechanics of the manufacturing supply chains, from the complexity, challenges and costs, is not readily available in the existing literature (Plotkin et al. 2017). This is partly due to the inherently challenging nature of vaccine manufacture, as outcome variability can be high from “the nearly infinite combinations of biological variability in basic starting materials” with factors ranging from the microorganism, the environmental condition of the microbial culture, the experience and knowledge of the manufacturing technician, the steps involved in the purification process, and even the analytical methods used to measure the biological processes and antigens present (Plotkin et al. 2017).

The Bill and Melinda Gates Foundation compartmentalizes the manufacture of commercial vaccines into four specific economic steps which are useful in consideration of the supply chain: (1) bulk: downstream and upstream production costs; (2) form/fill/finish: final dosage form and formulation (adjuvantation, lyophilization, etc.), aseptic filling, and remaining production finishing steps (vial labeling, etc.) costs; (3) secondary packaging: carton distribution preparation and warehousing costs; (4) QC/QA: quality control and quality assurance testing costs, which may occur at multiple points in manufacturing (Iqbal and Lorenson 2016). Within the bulk production, the upstream process is whereby the immunogen, the antigen that elicits an immune response, is generated through a cultivation process, and the downstream process is the purification process whereby the host cell impurities are removed and additional processing occurs to result in a bulk vaccine (Pujar et al. 2014). Overall quality controls ensure that the vaccine conforms to release specifications throughout its entire life cycle, including long-term stability tests required on several lots each year, adherence to all applicable National Regulatory Authorities (NRAs) and Current Good Manufacturing Processes (cGMP), maintaining proper process documentation and ratios of Quality Assurance personnel to production personnel (Plotkin et al. 2017).

Underlying each step of the manufacturing process is the consumable, the raw materials used as inputs in vaccine production, and consequently, their sourcing play a major role in the manufacturing supply chain and economics of vaccine development and production (Iqbal and Lorenson 2016). These consumables, stemming from biological processes themselves, are subject to variability in manufacturing, processing or contamination (i.e. materials of animal origin carry the risk of adventitious agents—viruses or other microbes—and therefore often sourced from disease-free regions) (Plotkin et al. 2017). Items such as facilities, equipment, direct labor and overhead including indirect overhead—plant management salaries, wages, training—and corporate overhead—executive salaries, centralized back-office functions, insurance—must also be accounted for as components or variables affecting the vaccine manufacturing supply chain, as well as commercialization and licensing (Iqbal and Lorenson 2016). Despite equipment commonalities across vaccine platforms, the specific cycles and sequences of operations varies to the extent that each product usually has a dedicated facility and group of experts, which allows for flexibility with unpredictable demand at the trade-off of higher cost (Plotkin et al. 2017). Furthermore, there is a global scarcity of personnel and labor with the skills, knowledge and expertise required by the vaccine industry, especially Quality Assurance personnel (Plotkin et al. 2017). Labor is also a necessary component of the supply chain that cannot be overlooked and must be factored as a component of resilient vaccine manufacture and distribution networks.

Table 22.1 provides an overview of the manufacturing supply chain and the general ecosystem surrounding vaccine production supply chains. It also shows constraints or stressors that may lead to disruptions in the manufacturing supply chain. Every vaccine is developed uniquely and as such this table is neither meant to be all-encompassing nor represent every vaccine, but to highlight general patterns in the supply chain as well as the inherent challenges in manufacture and

Table 22.1 General vaccine production and ecosystem surrounding vaccine manufacturing supply chains (Sanofi 2019; Plotkin et al. 2017; Iqbal and Lorenson 2016; VE 2016; Pujar et al. 2014)

	Bulk	Form/fill/finish	Packaging and lot release	QA/QC
Material	• Biological agents (e.g. yeast extract, E. coli, natural/ recombinant enzymes) • Chemical agents • Appropriate continuous cell lines and substrate • Associated raw materials and consumables for vaccine • Bioreactor (roller bottles, T-flasks, cell cubes, cell factories) • Microcarriers and serums • Centrifuges • Column and absorbent (e.g. alumina) • Sterilization materials	• Vials • Syringes • Needles • Stoppers • Seals • Buffers • Adjuvant • Stabilizers • Membrane filters • Preservatives (e.g. formalin) • Associated raw materials and consumables for drug product	• Labels (country specific) • Leaflets (country specific) • Vaccine Vial Monitors (VVM) • Secondary and tertiary cartons	• Inputs for testing kits • Assays • Documentation system of cGMP

(continued)

Table 22.1 (continued)

	Bulk	Form/fill/finish	Packaging and lot release	QA/QC
Operational	• Culture, harvest and extraction • Fermentation • Purification • Inactivation and valence assembly • Centrifugation • Chromatography • Contamination controls • Direct and indirect labor • IT systems • Facilities and maintenance • Raw material delivery (transportation and infrastructure) • Security • Material sourcing (logistics) • Inventory management • Utilities	• Filtration • Stabilization (e.g. pH management, lyophilization) • Adjuvantation • Aseptic filling and crimping • Contamination controls • Direct and indirect labor • IT systems • Facilities and maintenance • Raw material delivery (transportation and infrastructure) • Security • Material sourcing (logistics) • Inventory management • Utilities	• Single-product vs. multi-product operation • Direct and indirect labor • IT systems • Facilities and maintenance • Raw material delivery (transportation and infrastructure) • Licensing • Security • Material sourcing • Inventory and distribution management • Utilities	• Enhanced process control (e.g. PAT, QbD) • IT systems • Raw material delivery (transportation and infrastructure) • Security • Material sourcing • Inventory management • Utilities • Quality Assurance Personnel • Testing by manufacturer (raw material reception, API production coupling and formulation, filling, packaging) • Testing by exporting country (API production) • Testing by importing country (packaging and lot release)

(continued)

Table 22.1 (continued)

	Bulk	Form/fill/finish	Packaging and lot release	QA/QC
Constraint(s)	• Shelf-life • Biological variability • Processing scale • Facilities and equipment • Manufacturing dynamics and supply of consumables • Batch failure • Consumable quality and reliability • Tariffs/Nationalism/ closed borders due to quarantine	• Shelf-life • Biological variability • Processing scale • Facilities and equipment • Consumable quality and reliability • Batch failure • Consumable quality and reliability • Tariffs/Nationalism/ closed borders due to quarantine	• Shelf-life • Storage/warehousing • CTC or cold chain requirements • Facilities and equipment • Batch failure • Country-specific and population-specific labelling requirements • Tariffs/Nationalism/closed borders due to quarantine	• Variability within QA/QC testing • Licensing • Regulatory requirements • Inexperienced labor/regulators (with specific vaccine, product, regulation, etc.) • Tariffs/Nationalism/closed borders due to quarantine • NRA enforcement/compliance change/ country specific import/clinical trial requirements

scaling a vaccine supply chain. Platform vaccines do offer unique capabilities for efficient vaccine development, but due to their novelty, a large-scale manufacturing process has not yet been proven world-wide (HHS 2020d; Plotkin et al. 2017; Pujar et al. 2014). Consequently, strains on the supply chain have not been tested and hardened again risk and disruption.

Vital to vaccine manufacture is the cell line or culture that will be used. Historically, this has been conducted in vivo and in ovo meaning that vaccines still using these processes rely on sufficient supplies of live and pathogen-free eggs and animals, which can only accomplish scale-up through scale-out (i.e. increasing number of eggs) while using automation (Pujar et al. 2014). The in vitro production breakthrough, which came with the Polio vaccine, has been significant for industrial production that can now utilize either primary cells or continuous cell lines (e.g. Vero from monkey kidney cells, chick embryo fibroblasts, WI-38 and MRC-5 human diploid cells, MDCK from Mardin-Darby canine kidney) and cell-culture-based production systems, allowing for scale-up and relatively rapid shifts in production (Pujar et al. 2014). Furthermore, cell banking became a key feature of biomanufacturing allowing for stable and well-tested substrates for each vaccine batch, but require adherent surfaces for growth, which similarly limits scale-up with scale-out of surface area (Pujar et al. 2014). As such, microcarriers rather than bioreactors for production of new rabies and polio vaccines have been used for industrial purposes, with new vaccines now able to use serum-free media and suspension culture that is more conducive to scalability (Pujar et al. 2014). Each of these shifts in the upstream processing have simultaneously necessitated shifts in the underlying supply chains and changing biopharmaceutical technology. Likewise, corresponding changes to the downstream processing have also occurred (Pujar et al. 2014).

However, the shifting technology available to the vaccine industry, does not mean that "historic" vaccines have stopped being produced, having impacts on the supply chain as well. Most vaccines in use today were developed in the 1940s and 1950s and underscores that necessity of stable raw quality materials and component supplies from reliable vendors (Plotkin et al. 2017; Pujar et al. 2014). In addition to the cumbersome regulatory process, moving pharmaceutical manufacturing off-shore has also heightened the barrier to innovation, putting competitive advantage in cheap labor and environmental pollution regulations rather than new technology (Gurvich and Hussain 2020; Plotkin et al. 2017). These existing vaccine supply chains must be able to operate concurrently with ramping of new vaccines for pandemics, or other disruptions to the existing supply chains underpinning vaccine production.

In order to provide greater specificity on the supply chain, the vaccine type must be considered: live-attenuated vaccines, inactivated vaccines, live or whole-killed bacterial vaccines, subunit, recombinant, polysaccharide, and conjugate vaccines, toxoid and classical subunit vaccines, DNA vaccines, and recombinant vector and platform based vaccines (HHS 2020d; Pujar et al. 2014). Vaccines may also be multivalent, increasing their manufacturing complexity (Pujar et al. 2014) and as a

Table 22.2 Standard vaccine classifications and general manufacturing within the overall vaccine supply chain tiers/network. Note that this table is meant as an overview lo highlight overarching supply chain dynamics; every vaccine manufacturing process is uniquely developed and subsequently approved by NRAs for specific populations and must be identified individually for greater nuance in the manufacturing systems (Folegatti et al. 2020; Graham 2020; HHS 2020d; van Riel and de Wit 2020; Adalja et al. 2019; Pujar et al. 2014)

Vaccine type	Examples	Notable characteristics affecting vaccine supply chain	Upstream	Downstream
Live-attenuated	• Measles, mumps, rubella • Rotavirus • Smallpox • Chickenpox • Yellow fever	• Uses weakened form of virus—risk to immunocompromised • Complex upstream cultivation and minimal downstream processing • Scalability through continuous cell lines, microcarriers and serum-free suspensions • Life-time immunity • Cold chair	• Host/cell substrate choice vital—impacts to vaccine safety and reactogenicity • In ovo production still in use for some • Continuous cell lines/banks monitored for oncogenicity	• Harvest technologies and column chromatography for high levels of purification • Enhanced stabilization through lyophilization (but also risk of loss of potency) • Continued focus on lyophilization for improved thermostability
Inactivated	• Hepatitis A • Influenza (flu) • Polio • Rabies • Japanese encephalitis	• Uses dead form of the virus • Booster shots required • Scalability through continuous cell lines, microcarriers and serum-free suspensions • Cold chain	• Host/cell substrate choice vital—impacts to vaccine safety and reactogenicity • In vivo production still in use for some • In ovo production still in use for some • Continuous cell lines/banks monitored for oncogenicity • Microcarriers for continuous cell line scale-out over bioreactors • Serum-free media and suspension tor scalability • Development of "immortal" recombinant (designer) cell lines	• Harvest technologies and column chromatography for high levels of purification • Enhanced stabilization through lyophilization (but also risk of loss of potency) • Continued focus on lyophilization for improved thermo stability • Most require adjuvants (e.g. aluminum salts for enhanced immunogenicity, but increase manufacturing complexity

(continued)

Table 22.2 (continued)

Vaccine type	Examples	Notable characteristics affecting vaccine supply chain	Upstream	Downstream
Live or whole-killed bacterial	• Cholera • Typhoid fever • First whooping cough vaccine	• Simplest manufacturing bioprocessing of all vaccine • Lyophilization advancement for typhoid vaccine solid dosage form • Scalability through stirred tank fermenters with process monitoring and controls • Cold chain	• Cultivation of bacteria and harvesting • Inactivation as necessary with heat • Fed-batch fermentation for scalability—chemically defined medium in stirred tank fermenters (with aeration for aerobic cultures)	• Control of toxin production during fermentation • Suspensions formulated with formaldehyde • Enhanced process control through process analytical technology (PAT), Quality by Design (QbD) • Enhanced stabilization through lyophilization (but also risk of loss of potency) • Continued focus on lyophilization for improved thermostability
Submit, recombinant, polysaccharide, conjugate	• Hepatitis B • Hit (Haemophilus influenzae type b) disease • HPV • Whooping cough (DTaP combined vaccine) • Pneumococcal disease • Meningococcal disease • Shingles • Anthrax	• Uses specific pieces of virus—low risk to immunocompromised, but lower inherent immunogenicity • Acellular subunit vaccines address reactogenicity of the whole vaccine • Scalability through stirred tank fermenters with process monitoring and controls • Pnumovax®23 developed in the 1980s is the broadest valency vaccine • Cold chain	• Early media containing animal components (e.g. beef digest medium) • Shift to dairy media (e.g. casein digest), and to complete animal-derived component removal • Recombinant subunit requires rDNA technology • Conjugate reaction dependent on two high value intermediates; minimization of side reaction vital; scale-up through chemical processing (e.g. control rates of reaction via fluid transport) but complexity of vaccines ultimately limits	• Removal of cellular components and process residuals (extent varies with vaccine) • Purification may require precipitation using CTAB • High likelihood of contamination/intrusion requires batch fermentation and special facilities to prevent biocontainment • Most require adjuvants (e.g. aluminum salts) for enhanced immunogenicity, but increase manufacturing complexity

(continued)

Table 22.2 (continued)

Vaccine type	Examples	Notable characteristics affecting vaccine supply chain	Upstream	Downstream
Toxoid (classical subunit)	• Diphtheria • Tetanus	• Uses virus toxins • Booster shots required • Scalability through stirred tank fermenters with process monitoring and controls • Scalability through toxoid purification from precipitation and low-resolution chromatography to tangential flow membranes • Cold chain	• Early media containing animal component; (e.g. beef digest medium) • Shift to dairy media (e.g. casein digest), and to complete animal-derived component removal • Fermentation, harvest, centrifugation, and inactivation with formalin	• Extensive protein purification—ammonium sulfate precipitation, chromatography, membrane filtration • Most require adjuvants (e.g. aluminum salts) for enhanced immunogenicity. but increase manufacturing complexity
Recombinant vector and DNA (platform based)	Note to date	• Theoretically adaptable, streamlined and inexpensive with the same downstream/upstream processes for each platform (economies of scale not yet proven) • Long-term immunity • Scalable • NRAs continue to license product not platform • DNA poses challenging delivery methods • Cold chain (possible exception of DNA)	• Underlying identical mechanism, device, cell line, or delivery vector for multiple target vaccines (e.g. chimpanzee adenovirus) • Spectrum of platforms (VSV, ChAd, 17D, MVA, Baculovirus expression system, Tobacco plant cells, synthetic mRNA, DNA, self-amplifying RNA, nucleic acid printer) • mRNA-based provides additional manufacturing and biological delivery capabilities, target adaptability	• Purification required accounting for spectrum of platform types—viral vectors, expression platforms, nucleic acids, nucleic acid printer • Continuous antigen production limits to prevent desensitization

Table 22.3 WOS relevant publications with vaccine manufacturing supply chain models

Publication	Vaccine focus	Global focus	Process focus	Market focus	Quantitative/ qualitative	SC model	Associate network representation or discussion
Martin et al. (2020)	Late-stage vaccines	Developing countries	Distribution	Contract—global healthcare organizations	Qualitative	None—economic discount pricing	None
Graham (2020)	COVID-19	World-wide	Research and development	Global pandemic	Qualitative	None	None
Dixit et al. (2019)	N/A—literature review	N/A	Distribution, cold chain (manufacture excluded)	Healthcare supply chains	N/A	N/A	None
Souza et al. (2019)	National immunization program	Brazil	Distribution, cold chain	Logistics	Qualitative	None	Transportation
Wedlock et al. (2018)	Measles—rubella (MR)	Benin, India, Mozambique	Cold chain storage and wastage (reverse logistics)	Immunization campaigns	Quantitative—trade-offs between cost per dose and administered amount	HERMES-generated immunization SC model	Other vaccine networks (i.e. cold chain bottlenecks)
Ouzayd et al. (2018)	National immunization program	World-wide	Cold chain	Real-time tracking	Quantitative	SCOR model and colored petri net theory	Transportation
Hovav and Herbon (2017)	Large-scale influenza vaccination program	World-wide; Israeli case study	Distribution	Healthcare organization/ services	Quantitative—trade-offs with cost and population coverage	Mixed-integer programming optimization model	Transportation

(continued)

Table 22.3 (continued)

Publication	Vaccine focus	Global focus	Process focus	Market focus	Quantitative/qualitative	SC model	Associate network representation or discussion
Chick et al. (2017)	Influenza vaccination program	Conceptual	Procurement	Contract—Government Healthcare Programs	Quantitative—trade-offs with production yield, procurement, government oversight resources	Game theory—optimization with asymmetrical information	None
Thompson and Tebbens (2016)	Global immunization programs; measles and cholera case studies	World-wide	Universal vaccine stockpiles	Policy—global healthcare organizations	Qualitative	Stock-and-flow	Transportation; other vaccine interventions
Hansen and Grunow (2015)	Secondary pharmaceutical production (i.e. downstream of API)	Conceptual	Manufacturing ramp-up capacity	Pharmaceutical industry	Quantitative	Mixed-integer linear programming	Construction time
Chen et al. (2014)	Global immunization programs	Developing countries; Niger, Thailand, Vietnam case studies	Distribution networks	WHO's Expanded Program on Immunization (EPI)	Quantitative	Linear programming	Transportation; capacity expansion

(continued)

Table 22.3 (continued)

Publication	Vaccine focus	Global focus	Process focus	Market focus	Quantitative/ qualitative	SC model	Associate network representation or discussion
Levner et al. (2014)	Large-scale influenza vaccination program	World-wide; Israeli case study	Supply chain risk	Healthcare organization/ services	Quantitative—trade-offs with manufacturing, distribution, inventory cost: with public benefit	Integer programming on reduced SC with extension of classical Shannon's entropy concept (information theory); GAMS software	Transportation
Anderson et al. (2014)	Global immunization programs	Laos	Cold Chain Information System (CCIS)	UNICEF and Lao Ministry of Health	Quantitative—real time measurements of inventory and temperature	None	None
Norman et al. (2013)	Global immunization programs (set list of vaccines)	Conceptual network	Cold chain—passive cold storage devices (PCDs)	WHO's Expanded Program on Immunization (EPI)	Quantitative—economic trade-offs between portable/stationary PCDs, and solar refrigerators	Graph SC with economic scenarios	Transportation
Arifoğlu et al. (2012)	Influenza vaccination	Conceptual networks	Allocation of Final Product	Social planners (e.g. governments)	Quantitative—comparative economic interventions	Numerical equilibrium analysis	None

(continued)

Table 22.3 (continued)

Publication	Vaccine focus	Global focus	Process focus	Market focus	Quantitative/ qualitative	SC model	Associate network representation or discussion
Lee et al. (2012)	Pneumococcal (PCV-7) and rotavirus vaccines (RV)	Niger	Routine immunization programs (i.e. impacts on other vaccine SCs)	WHO's Expanded Program on Immunization — (EPI); Bill and Melinda Gates Foundation	Quantitative—supply ratios	Linear SC model	Transportation; other vaccine networks
Lee et al. (2011a)	Pneumococcal (PCV-7) and rotavirus vaccines (RV)	Thailand	Routine immunization program: (i.e. impacts on other vaccine SCs)	WHO's Expanded Program on Immunization (EPI); Bill and Melinda Gates Foundation	Quantitative—baseline vaccine comparisons	HERMES-generated SC and deterministic mathematical equation-based modeling	Transportation; other vaccine networks
Smith et al. (2011a)	Measles containing vaccine (MCV)	World-wide	Manufacturing capacity	World Health Organization	Quantitative—population dynamics and projected supply	None	None
Assi et al. (2011)	Measles	Niger	Distribution—vial size	WHO's Expanded Program on Immunization — (EPI); Bill and Melinda Gates Foundation	Quantitative—trade-offs with cost, storage, availability, transport, wastage, disposal	HERMES-generated SC, discrete event simulation model	Transportation

(continued)

Table 22.3 (continued)

Publication	Vaccine focus	Global focus	Process focus	Market focus	Quantitative/ qualitative	SC model	Associate network representation or discussion
Lee et al. (2011b)	Measles (MMR)	Thailand	Distribution—vial size	WHO's Expanded Program on Immunization - (EPI); Bill and Melinda Gates Foundation	Quantitative—trade-offs with wastage, administration costs, and reserve decrease	Linear supply chain	Transportation

result, increasing supply chain complexities. Table 22.2 further breaks down these vaccine specifics within the manufacturing supply chain ecosystem.

Overall, there are very few academic or publicly available industry publications focusing on the specifics of the manufacturing supply chain, and those that do generally focus on aspects pertaining to either economics of manufacturing, the global humanitarian immunization effort, or a combination of both. Publications looking at modeling the manufacturing supply chain are even more limited. For example, a Web of Science "All Databases" topic search with no time limit (i.e. 1864 to November 1, 2020) and no citation requirements for "vaccin*" AND "manufactur*" AND "supply chain*" AND "model*" resulted in 28 publications. Of these, 20 were relevant to vaccine supply chain manufacturing and focused on modeling aspects of the network. These publications are shown in Table 22.3. None of these publications specifically analyze resilience, although one focuses on risk by limiting the intricacy of the supply chain modeled and employing entropy modeling to increase public benefit to influenza campaigns (Levner et al. 2014). Although many of the publications provide quantitative analysis and develop supply chain models, their focus remains limited to vaccine types, countries, specific portions of the manufacturing (or overall) vaccine supply chain, meeting immunization targets without actual analysis of the manufacturing supply chain, or non-inclusive of associated networks. In order to harden vaccine supply chains against disruptions, they first need to be modeled using network analytics, starting with manufacturing, and then understood through resilience analytics. (Note that there are two publications, however, under the larger topic vaccine supply chain resilience, that are returned when eliminating "model*" and "manufactur*" and this is discussed in Sect. 22.3.1.)

One strategy to improve the resilience of the vaccine supply chain is for modular manufacture. For example, the Bill and Melinda Gates Foundation focuses on strategies for both novel delivery formats as well as modular, automated manufacturing platforms enabling small-batch vaccine production (Gates 2020). However, the benefit of large-scale manufacturing of vital vaccines has been revolutionary for global immunization targets (Pujar et al. 2014). Conversely, the high cost of entry for vaccine manufacture limits the potential profit of developing countries to invest and produce their own vaccines due to the equipment, personnel, consumables necessary (Plotkin et al. 2017). Although this would be a similar shift in the supply chain as that seen in 3D printing for PPE during supply chain disruption, the vaccine industry is significantly regulated and vaccine safety and efficacy of paramount importance.

Another strategy that can be employed at the manufacturing stage of vaccine supply chains to help buffer against sourcing disruptions is stockpiling. However, this has been more commonly used as a tool for finished products, where distribution scenarios (last mile) may impact the progression of pandemic spread (Davey et al. 2008). Long-term focus on commercialization optimization within the manufacturing of vaccines and preceding tiers rather than manufacturing optimization (i.e. consideration of all the networks) can similarly decrease risk of disruption, prioritizing long-term cost savings over short-term revenue (Plotkin et al. 2017).

This includes ensuring that stable manufacturing supply chains are available for commercialization so that immunization goals are met. Understanding the entire supply chain through network analytics is imperative to long-term success. Given the risks in manufacturing and unanticipated (or even anticipated) disruptions, a more resilient manufacturing supply chain will be able to continue converging its operational maximum capacity to its theoretical maximum capacity post disruption, causing less disruptions in the remainder of the supply chain.

22.2.3 Cold Chain

As most vaccines must be kept within narrow temperature ranges between 2 and 8 ° C, a specific "cold chain" process for manufacturing, distribution, storage and administration of these vaccines to ensure potency, effectiveness and ultimate safety for populations is necessary, beginning with temperature control at the manufacturing plant and extending through transportation and administration to the patient (Kumru et al. 2014; CDC 2019; UN 2020). The CDC further breaks the cold chain into responsible agents, with the manufacturer responsible for temperature control at the "vaccine manufacturing" stage, the manufacturer and distributor both responsible at the "vaccine distribution" stage, and the provider responsible at the "vaccine arrival at provider facility," "vaccine storage and handling at provider facility," and "vaccine administration" stages (CDC 2019). In other words, any disruptions in the cold chain are considered off-label use, putting liability on the individual practitioner (Purssell 2015). Even if the equipment for the cold chain is in place, proper protocols and procedures must be in place among the adjoining networks—personnel must be trained properly and transportation available.

Having a cold chain that is capable of responding to different vaccine requirements is essential, as some vaccines such as live, attenuated viral vaccines are sensitive to elevated temperatures, whereas some cannot be frozen such as aluminum adjuvanted vaccines (Kumru et al. 2014). The cold chain aims to limit vaccine exposure to inappropriate conditions due to irreversible impacts to potency if outside recommended temperature ranges, as well as complete destruction of potency if frozen (CDC 2019). There is often no visible evidence that potency has been lost or destroyed and can only be determined through expensive laboratory assays only cost-effective at scale (Galazka et al. 1998; CDC 2019). Although the cold chain poses elevated challenges in warmer climates with longer distribution legs, the challenge lies in keeping the product within a constant temperature range, not necessarily the cold temperature itself (Gunn 2020).

Most pharmaceutical companies rely on service providers for distribution of temperature dependent products. Pfizer, for example, coordinates logistics through a system of rigorous oversight and audits with third-party distributors (Gunn 2020). However, aid organizations, such as Doctors Without Borders (MSF) have set up an end-to-end supply chain and coordinate the entire vaccine distribution process (Gunn 2020). The MSF biopharmaceutical supply chain is based on three supply centers in Europe, before passing through the technically challenging last mile of the cold chain that could be thousands of miles long (Gunn 2020). In the case of the Ebola epidemic, the rVSV-ZEBOV vaccine by Merck has a 97.5% effectiveness rate, but must be stored at −70 to −80 °C, leaving logistics and supply chain implementors to use ice-lined generator- and solar-powered refrigerators that can meet temperature requirements during power failure (Gunn 2020).

The MSF Ebola vaccine distribution highlights the use of both passive and active cold chain equipment (CCE) used for storing and transporting vaccines. Active CCE includes mains refrigerators, which are cooled through compressors powered by an existing electric grid, and off-grid refrigerators, which are cooled through either absorption (burning liquid petroleum gas or kerosene) or solar powered compressors (solar battery-powered or solar direct-drive) (Robertson et al. 2017; Chen et al. 2015). In passive CCE, the cooling is provided through coolant packs of phase changing material (PCM) and includes devices such as cold boxes and vaccine carriers (Robertson et al. 2017; Chen et al. 2015). CCE is so vital to the vaccine supply chain, that the World Health Organization has a list of approved CCE and recommended uses available to the public (WHO 2017). These approved devices are not a cure-all, however, and must be used properly. The passive cooling devices, for example, will cause freeze damage to vaccines if conditioning of the coolant packs is not conducted prior to placement of the vaccines (Robertson et al. 2017).

Emerging technologies such as remote temperature control and satellite tracking are already being used to manage risk in cold chain operations (Ouzayd et al. 2018; Anderson et al. 2014). Incorporation of remote sensors in vaccine shipments allows for targeted intervention and better understanding disruptions to the cold chain. One company, Parsyl, found that the biggest risk to vaccines in the cold chain was freezing and not heat, and that in one instance although one fourth of vaccines experienced freeze damage, only 5% of fridges were responsible (Hubbard 2020). Improved monitoring and data analysis of disruptions to the cold chain can greatly improve outcomes. FedEx has also launched its own sensor tracking technology, SenseAware ID, with healthcare, aerospace and retail industries expected to receive enhanced data on their shipments starting in November 2020, including those requiring cold chain, thermal blankets, and temperature controlled environments (FedEx 2020).

Some research also attempts to circumvent the cold chain in its entirety, through such means as eliminating the need for adjuvant (Sun et al. 2016) or using dried viral vaccines in a pullulan and trehalose mixture (Leung et al. 2019). The latter enables the vaccines studied to retain efficacy for at least two months at 40 °C and at least 3 months at 40 °C through the use of prior approved FDA materials (Leung et al. 2019). However, despite the use of existing materials, the research team acknowledges that the pharmaceutical and logistics industry, as well as NGOs and governing bodies, are already heavily invested in the cold chain (Cooney 2019). Therefore, even given the simple technical solution, the McMaster University research group does not anticipate a large-scale vaccine supply chain shift (Cooney 2019).

22.2.4 Last Mile

Of particular importance for the vaccine supply chain, further differentiating it from traditionally studied supply chains, is the "last mile." This encompasses getting the vaccine product to the end user in a medically compliant manner. One CDC estimate puts the value of vaccines destroyed due to improper storage and transportation at $300 million per year (Gunn 2020). Similarly, one study out of Ontario, Canada put 20% of the points of vaccination (physician offices and healthcare facilities) as noncompliant with vaccine storage and handling, amounting to $3 million of wasted vaccines annually in Ontario alone (Weir and Hatch 2004). The last mile not only has monetary impacts, but severe impacts on human health. For example, in Kapoeta, South Sudan 15 children died of improperly stored measles vaccines in May 2017 (Gunn 2020). Without simultaneously understanding the network required for the vaccine supply chain and how to plan, absorb, recover, adapt to disruptions, human life is at stake.

In tandem with new technologies such as drone delivery (Forde 2019), new vaccine management strategies such as "Controlled Temperature Chain" (CTC) are also being developed to improve economic viability and outreach of vaccine supply chains, especially in the last mile (Controlled Temperature Chain Working Group 2017). Vaccines developed and subsequently labeled for CTC supply chains are able to enter ambient temperatures less than 40 °C for a number of days prior to administration, simplifying storage, transportation and time constraints of the last leg of the traditional cold chain, as well as eliminating the need for medical worker time spent conditioning ice packs prior to vaccination campaigns (Controlled Temperature Chain Working Group 2017).

22.2.5 Reverse Logistics and (Biohazard) Waste Management

Due to various CCE requirements, such as reuse of phase changing materials (PCM) in passive cold chain, and medical waste requirements of immunization equipment and associated medical devices, models of the vaccine supply chain must also specifically incorporate waste management and reverse logistics into their networks. Mass vaccine campaigns must ensure that not only the proper protocols for cold chain storage are maintained, but also proper protocols are followed for waste disposal as new vaccination centers are set up (Toner et al. 2020). Furthermore, due to the sensitive nature of vaccines, strict adherence to expiration dates must be followed and as such pharmaceutical reverse distributor programs are available to collect unused single-dose or multi-dose vials, and manufacturer-filled syringes of vaccine or diluent (MHS 2020). One development that would impact waste management is the technology for needleless flu vaccines. These are envisioned to be dispensed as patches that do not require cold chain, can be administered in rapid large batches, and do not require disposal or reuse of needles (Hayes 2019; Wedlock et al. 2019).

Another nuance of the vaccine supply chain is the likelihood of wasted vaccine itself, or “open vial waste” and the trade-offs between single-dose formats and multi-dose formats. Such trade-offs include the higher filling costs, vaccine overfill adjustments, storage requirements, medical waste and packaging costs for lower dose vial formats, and the “open vial waste” of higher dose vials (Lee et al. 2010; Assi et al. 2011; Haidari et al. 2015). Some vaccines are packaged as multi-dose vials for use during a vaccination session intended to serve more than one individual, but if the number of doses within the vial does not match the number of people at the session, then the remaining vaccine must be disposed of and is termed “open vial waste” (Chen et al. 2015). Lee et al. use an economic computational model do understand thresholds for single-dose and multi-dose vaccine formats for measles (MEA), Hemophilus influenzae type B (HiB), Bacille Calmatte-Guerin (BCG), yellow fever (YF) and pentavalent (DTB-HepB-Hib) (Lee et al. 2010). They find that for MEA, the single-dose vial should be used for up to 2 patients per day and the 10-dose above; for BCG the 10-dose vial should be used for up to 6 patients per day and the 20-dose above; for Hib the single-dose vial should be used for up to 5 patients per day and the 10-dose above; for YF the 5-dose vial should be used for up to 33 patients per day and the 50-dose above; for DTB-HepB-Hib the single-dose vial should be used for up to 5 patients per day and the 10-dose vial above (Lee et al. 2010). It is important to note that this model does not consider the increased chance of contamination with multi-dose administration (Lee et al. 2010). Building on this, Haidari et al. address optimal primary vaccine container size by also specifically modeling the Benin vaccine supply chain through the HERMES software platform, finding that the larger dose containers reduced supply chain bottlenecks, but ultimately recommending that vaccine supply chains be individually modeled similar to other industries in accordance with specific locations, stakeholder goals, government policies, populations and health worker training (Haidari et al. 2015). Despite using a more complex supply chain model with transportation and C2 characterizations, similar to Lee et al., Haidari et al. also neglect to include the greater user error and propensity for contamination found in large-dose containers (Lee et al. 2010; Haidari et al. 2015). Although these results are intended to guide vaccine developers, manufacturers, distributors, and purchasers through larger network analyses, disruptions—anticipated or not—have not been considered, which could compromise a vaccine program (Lee et al. 2010).

22.2.6 Vaccine Supply Chains and Interconnected Networks

Although vaccine supply chains do not operate independently of other networks, such as transportation and public health policy (i.e. C2 network), few publications directly address the associated network intricacies of the vaccine supply chain. One study analyzes existing transportation and storage capacity of the vaccine supply chain in Thailand with varying time frames and target populations, finding that transportation bottlenecks are a significant issue (Assi et al. 2012). Another example is the United States health care supply chain, which relies heavily on Chinese manufacturing, which plays an interconnected role with vaccine administration for products such as PPE (Sutter et al. 2020).

In the United States, of the pharmaceutical companies that responded to the 2019 HDA Research Foundation survey, 100% of distributors stock cold chain products, with distributors ranging from traditional, specialty to third party logistics providers (HDA 2019). However, only 40% responded that they monitor and record the temperature of products in transit (HDA 2019). If manufacturers are to expand their shipments of temperature dependent vaccines in response to global epidemics, the distributors they rely on for normal pharmaceutical supply chains will need to ensure their cold chains are able to handle the demand, and necessitates incorporation into the supply chain models.

Optimization tools can also be used to coordinate supply chains relying on similar underlying networks. Due to the cold chain infrastructure required of the vaccine supply chain, the earlier comparisons with agriculture can be extended, with the food supply cold chain and global efforts to minimize food waste and capacitate rural farmers (UN 2020). Initiatives such as the United Nations Environmental Program are combining efforts in their cold chain initiatives so that food and vaccine can use the same supply chains, calling for "resilient, reliable and sustainable cold chains" and seek to pivot away from traditional methods of large-scale refrigeration in order to reduce fossil fuel and refrigerant use, while increasing availability (UN 2020). Analytic tools including value of information on vaccine inventory levels, and trade-offs with visibility and cost are also examples that can be used (Li et al. 2018).

Public opinion towards vaccines is also an associated network that has had impacts on successful vaccination campaigns, with misinformation expected to increase as new vaccines are developed (Larsson 2020). For example, the New Jersey Department of Health found that once available, only 60% of surveyed physicians and 40% of surveyed nurses would get vaccinated (Walsh 2020).

22.2.7 MMR and Smallpox Vaccine Case Studies

The measles-mumps-rubella and smallpox vaccination programs underscore the importance of the entire vaccine supply chain and the associated networks and domains such as transportation, social, C2, etc. Measles was responsible for over two million deaths annually prior to the introduction of the Expanded Program on Immunization (EPI) in the 1980s (WHO 2019). Although current vaccine immunization programs and supplementary mass preventive vaccination campaigns are estimated to have prevented 21.1 million deaths globally, annual deaths due to measles remain at 100,000 (WHO 2019). Despite an efficacious vaccine, rubella also continues to be a global health priority (WHO 2019). Due to high transmission rates, measles and rubella outbreaks are used by public health officials to assess overall immunization gaps (WHO 2019). This ultimately serves as vaccine supply chain viability litmus tests, which could also potentially be linked to disruption.

As of September 2019, 82 countries were considered to have eradicated measles and 81 rubella (WHO 2019). Country eradication can be reversed, however, as countries face insufficient political will, conflict, migration, humanitarian emergencies, lack of vaccine investment and "vaccine hesitancy" (WHO 2019). The M-M-R II vaccine requires cold chain, but does not lose potency if frozen, making it less susceptible to disruptions along the supply chain (DHA 2019). In fact, it can be used to buffer other vaccines from freezing (WHO 2015). Seven countries once having been declared measles free have already re-established virus transmission, regardless of this flexibility in the cold chain (WHO 2019). As such, an MMR vaccine that is independent of the cold chain or skilled health-care workers for distribution would be advantageous on the global scale (Lambert et al. 2015).

Smallpox, on the other hand, was considered completely eradicated when the 33rd World Health Assembly, on May 8, 1980, officially declared the world free of smallpox (CDC 2016). Smallpox is transmissible from human to human in dense populations, but is not considered to be highly transmissible and outbreaks were not associated with locations like schools or trains; though three out of ten contracting the disease died (Belongia and Naleway 2003; Peterson et al. 2015; CDC 2016). Although mass vaccination was the original approach, the smallpox eradication program ultimately employed the "ring" vaccination strategy to reach complete eradication, strategically targeting hot spots and contacts of known cases to break the chain of transmission (Belongia and Naleway 2003; CDC 2016; Toner et al. 2020). The eradication program was initiated by the World Health Organization in 1959, but a lack of funds and personnel rendered it unsuccessful until it was relaunched in 1967 as the Intensified Eradication Program with the goal of 80% vaccine coverage in every country through increased global laboratory coverage providing higher-quality vaccine, development of the bifurcated needle, and use of the ring vaccination or surveillance system (Belongia and Naleway 2003; CDC 2016).

Dryvax, the vaccine that was used for the smallpox eradication programs, does require refrigeration, and cannot be frozen, but the success of the eradication campaign is partially attributed to its long-term stability outside of cold temperatures (Belongia and Naleway 2003; Wyeth 2004). More recently, Dryvax was replaced by a couple other vaccines with fewer side effects, including ACAM2000 in the U.S. strategic stockpile in case of bioterrorism, but continues to require the cold chain (Peterson et al. 2015; Emergent 2018). The global eradication of smallpox is considered by some one of the greatest achievements in human history (Belongia and Naleway 2003). Not only the manufacturing and technological advances in vaccines were vital, but smart distribution and last mile policies and supply chains.

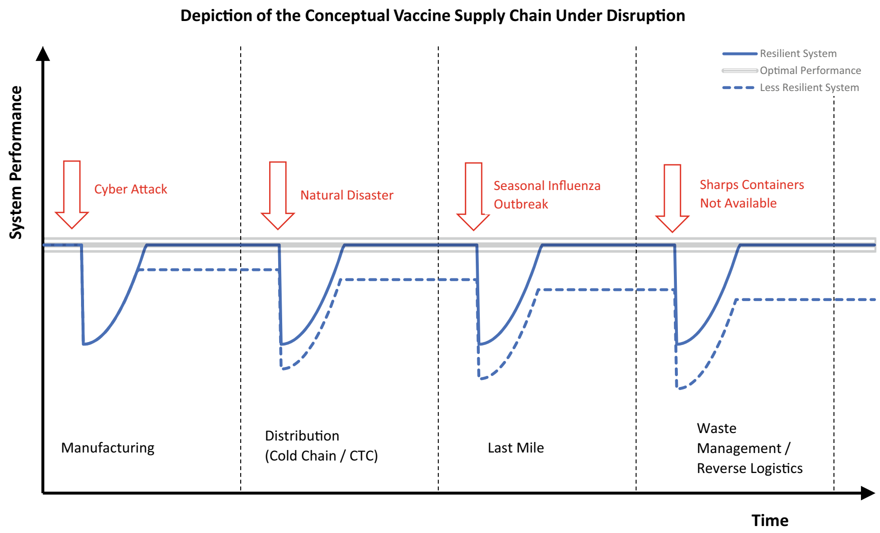

Fig. 22.2 Notional comparison of a resilient and less resilient vaccine supply chain experiencing examples of disruptions during different stages of the vaccine supply network. Note these possible disruptions are not unique to any stage

22.2.8 Vaccine Supply Chain Disruptions

Most disruptions in the vaccine supply chain have been studied in the context of expected disruption to power supply in the cold chain. Chen et al. develop a model addressing cost tradeoffs for passive CCE design within the Niger vaccine supply chain with variables including ice recharging, vaccine storage space, storage volume, doses per vial of vaccine, vial volume, truck loads, vaccine packing ratio, and ice packing ratio, among other variables (Chen et al. 2015). There are historic examples of short-term disruptions, however. In 2008, Turkey experienced a disruption to its vaccine supply chain when the first generation of pneumococcal vaccine was introduced, more than quadrupling their cold storage requirements from 2,600 to 11,400 m^2, and ultimately had to rent cold storage space (Humphreys 2011). And in 2016, an explosion at a Chinese factory caused a shortage of the broad-spectrum antibiotic piperacillin-tazobactam due to traditional manufacturing of active pharmaceutical ingredients (APIs) localized at only a few factories (Cogan et al. 2018). The 2017 back-to-back hurricanes Irma and Maria devastated Puerto Rico, which in 2017 accommodated over 70 medical device manufacturers and 49 pharmaceutical companies, producing about 10% of the U.S. drug supply and a larger share of the U.S. IV solutions (Stone 2018). In response to the subsequent shortage, the FDA approved imports from additional countries and animal sources, while also extending the expiration date on available IV fluids (Hayes 2018; Stone 2018).

The vaccine supply chain is also especially susceptible to manufacturing disruptions as specific vaccines rely on specific processes and therefore specific and sustained raw materials, meaning that competitive pressure from within the industry or even other industries could not only potentially increase cost, but also interrupt the supply chain (Plotkin et al. 2017). Global vaccine availability hinges on the delivery of potent and effective vaccines at point of use through reliable distribution channels, strict quality control and in-depth production methods and raw material sourcing at manufacture (Smith et al. 2011a, b). Consequently, a disruption at any node or link could have devastating human impacts. Even so, most of the existing literature looks at optimizing the reach of vaccines in developing countries under known and expected disruptions (e.g. unreliable electricity grids and intermittent transportation infrastructure), but what about unanticipated disruptions to the global vaccine supply chain and their associated networks? Disruptions are inevitable in supply chains of this magnitude, underscoring the need for ensuring resiliency of the network (Linkov et al. 2021). These "unknown unknowns" can only be understood through resilience analytics of vaccine supply chain models.

Analyzing and modeling how a supply chain will react to disruption is vital to ensuring distribution targets are met. A resilient vaccine supply chain will continue to achieve immunization targets post disruption while a less resilient supply chain may leave already marginalized populations without recommended immunizations (see Fig. 22.2 for depiction).

22.3 Supply Chain Models and Resilience Analytics

An efficient and resilient vaccine supply chain is fundamental for achieving a wide-spread and equitable immunization response. Although at the heart of any immunization program is the vaccine itself, experts in the immunization field have the mantra, '*no product, no program*' calling attention to the fact that the network of staff, equipment, vehicles, and data is equally as important as the existence of a vaccine (Moeti et al. 2017). In other words, without a supply chain and its associated networks, a vaccine cannot meet intended public health goals. And even with an efficient supply chain, if it is not resilient, it will not maintain optimal functionality after an inevitable disruption. As such, quantitative vaccine chain models and resilience analytics are warranted.

22.3.1 Lack of Existing Academic Publications on Vaccine Supply Chain Resilience

A topic search in Web of Science (WOS) "All Databases" for relevance to "supply chain*", "vaccin*" and "resilien*" returned only two results. The first publication is

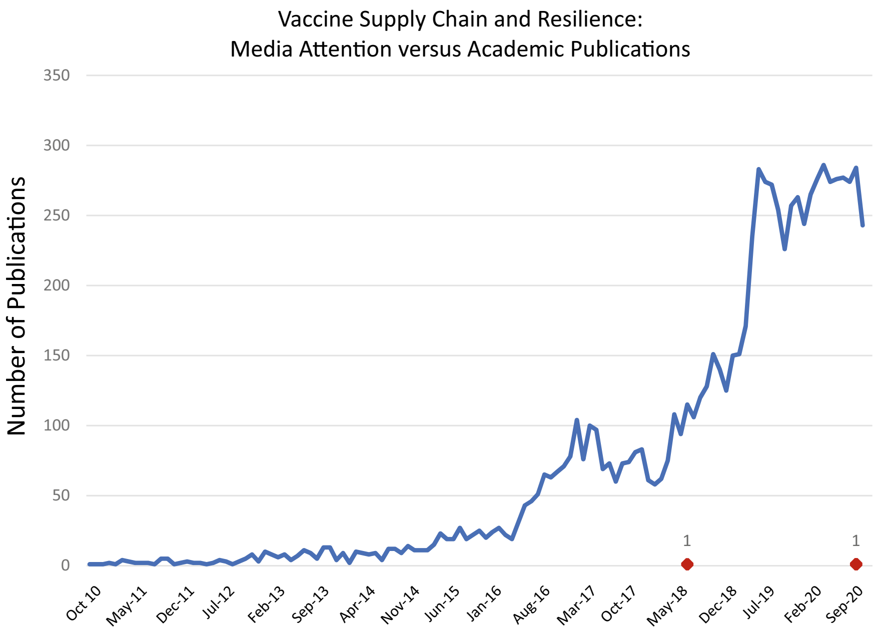

Fig. 22.3 Number of available Google News results on a monthly basis (blue) as compared to published scholarly articles found on Web of Science (red), showing lag in academic research

a review article that does not provide a fundamental definition of resilience and minimally addresses supply chain, but does acknowledge the constraints of cold chain (Tambo et al. 2018). The authors do point out "strengthening acceptable and effective intervention packages requires multidisciplinary and intersectoral linkage," but offer no models or quantitative methods for policy makers (Tambo et al. 2018). The second publication focuses on veterinary vaccine supply chains and does not offer metrics for measuring supply chain resilience (Dungu 2020). However, Dungu does offer a valuable discussion on types of vaccine banks that improve resilience of vaccine supply chains, by defining (1) physical vaccine banks—storage of ready-to-use single or multi dose vaccines; (2) virtual vaccine banks—an agreed upon amount of vaccine can be produced and ready for distribution in a certain amount of time should the need arise; (3) maintenance of production capacity—consistent management of vaccine seed material and ensuring supply chains are in place (2020). The latter is most critical for pandemics as existing infrastructure and material could be adapted to any disease. For example, the U.S. keeps a stockpile of chicken eggs for use for influenza vaccines (BARDA 2020). However, this hedge will not help for newer vaccine development technologies, such as many of the coronavirus vaccines under development, as different vaccine mechanisms are being used (Yeung 2020). New vaccine technologies, such as those that are platform-based, offer rapid scale and delivery, which could be vital for stockpile replenishment during outbreaks, offering a "warm-base" (Adalja et al.

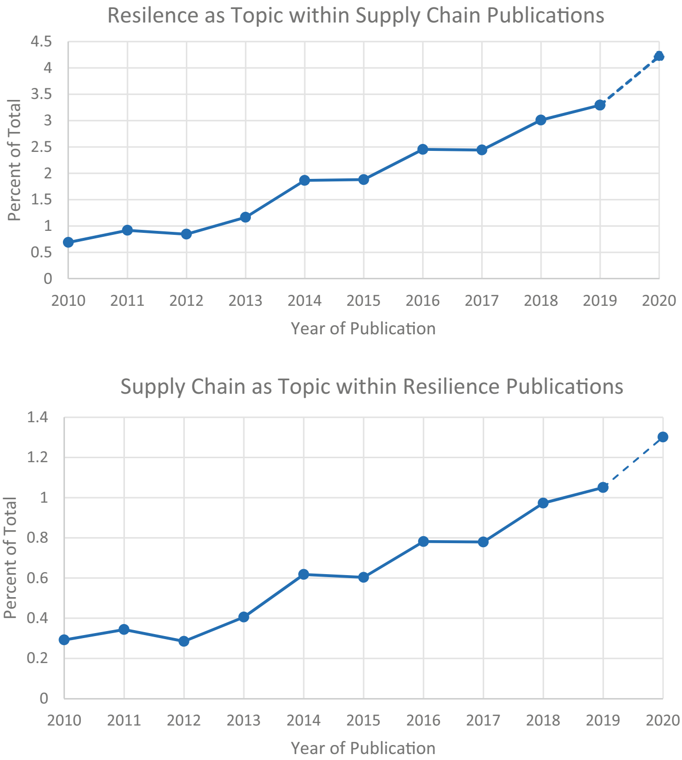

Fig. 22.4 Share of supply chain publications discussing Resilience (**a**) and share of resilience publications discussing supply chains (**b**) from WOS October 11, 2020 topic searches. Data for 2020 may be incomplete

2019), potentially hardening the vaccine manufacturing ecosystem against risk and increasing the resilience of the vaccine supply chain.

Due to the lack of academic publications, a media search using the same WOS topic search criteria was conducted on October 19, 2020 using the Google News search engine for historical searches for each month from October 2010 to September 2020. Media attention specifically pertaining to the vaccine supply chain and resilience has been on the rise (see Fig. 22.3), with many news sources focused on humanitarian vaccination and immunization developments, especially with the rise of vaccine initiatives by the Bill and Melinda Gates Foundation and its partners. Some of these publications look at emerging technologies in vaccine development, while others promote the benefits of private-public cooperation (Hoybraten 2014). The Ebola epidemic is also a common theme. There is also a theme among news feeds showcasing drawbacks of concentrated manufacture in China, including the presence of contaminated vaccines and further need for oversight at the beginning of the supply chain (SDC 2018). Since the beginning of the COVID-19 pandemic, google news searches have returned articles pertaining to expected logistics shortcomings and supply chain bottlenecks for implementing a vaccination campaign once the vaccine has been approved. Of note, some U.S. publications did point out shortcomings in the existing domestic supply chain prior to the pandemic, such as "Fragile Antibiotic supply Chain Causes Shortages and Is a National Security Threat," which points to the fact that 80% of the U.S. pharmaceutical raw materials come from China and India (Stone 2018). One estimate puts the number of drug shortages as having tripled between 2006 and 2018, putting blame on pharmaceutical manufacturers moving to countries such as China and Brazil, citing issues such as security, intellectual property and conflicting government policies (Morris and Sweeney 2019). One article does analyze uncertainty in the vaccine supply chain (Comes et al. 2018). Although Comes et al. do not specifically look at resilience in vaccine supply chains, they show the need for planning and implementing cold chains under uncertainty, through two complementary approaches: "adaptive policymaking" and "adaptation pathways" (Comes et al. 2018).

Resilience of the vaccine supply chain is critical. However, a lack of models, metrics and network analytics continues to plague the academic vaccine supply chain resiliency field.

22.3.2 Supply Chain Resilience Publications—Modeling Trends

Although the vaccine supply chain presents unique challenges, prior research on quantitatively modeling resilience in supply chains shows (1) a lack of the four-stage NAS definition of resilience (plan, absorb, recover, adapt); (2) a lack of modeling disruptions of different magnitude, likelihood and systemic threats; (3) lack of the tiered approach to modeling; (4) lack of modeling associated networks that constitute value generation (e.g. C2—command and control, transportation, cyber) (Golan et al. 2020; Mersky et al. 2020).

The supply chain resilience field is rapidly growing, as indicated by the Web of Science "All Databases" search, with the share of supply chain publications over the past ten years discussing resilience jumping from 0.7% in 2010 to 4.2% in 2020 (Fig. 22.4a). Similarly, the portion of resilience publications focused on supply chains have also increased from 0.3% in 2010 to 1.3% in 2020 (Fig. 22.4b). Note that these publications may not use the term "resilience" as defined by NAS, but have been tagged as relevant by Web of Science, indicating relative trends in the field.

Of note, although not included in the academic search, there are some private companies that offer resilience benchmarks to their clients. Resilinc Corporation, for example, emphasizes its capability to map multiple tiers of the supply chain and monitor disruptions through social media monitoring (Resilinc 2017). This emphasis on visibility allows Resilinc's clients in the pharmaceutical industry to quickly pivot to other sources as soon as a possible disruption is detected in a

Table 22.4 Resilience Characteristic Results for 2020

Publication	Plan	Absorb	Recover	Adapt	Metric	SC	Trans.	Decision	Scenario
Ivanov, D. March 2020 (a)	No	Yes	Yes	No	Proxy	Graph	Graph	Optimization	Case study
Ivanjov, D. May 2020 (b)	No	Yes	Yes	Yes	Proxy	Graph	Graph	Optimization	Set list
Ivanov, D. and Dolgui, A. April 2020 (a)	No	Yes	Yes	Yes	No	Graph	None	Optimization	None
Ivanov, D. and Dolgui, A. May 2020 (b)	No	Yes	Yes	No	No	Graph	Graph	Optimization	Case study

supplier they may not have otherwise known is affiliated with their supply chain, such as with Biogen during hurricanes Harvey, Maria and Irma hitting Puerto Rico (Resilinc 2017). This R Score™ can range on a scale of 1 to 10 and is a weighted average that factors (1) transparency of information; (2) network locations in relation to factors such as geographical dispersion, geopolitical stability, natural disaster resistance, and macro-economic strength; (3) continuity of recovery time capabilities at company sites; (4) performance regarding financial stability, quality, and responsiveness; (5) supply chain resiliency program maturity (SCRM), which encompasses ongoing efforts by the company for supply chain visibility and monitoring, and proactive risk management (Resilinc 2017). This score can then be used to compare improvements quarterly within a company as well as benchmark against other companies within the same industry to improve supply chain resilience.

22.3.3 COVID-19 Current Trends and Impacts on Supply Chain Resilience

Understanding the system dynamics from disruptions due to the COVID-19 pandemic on existing supply chains is essential to developing resilient vaccine supply chains that must achieve optimal performance while experiencing impacts from the pandemic itself. Building on the results from the 2020 review of resilience analytics in supply chain modeling for trends through the end of 2019 (see Golan et al. 2020 for full discussion), publications from the year 2020 were analyzed with the additional cross section of the COVID-19 Pandemic. Specifically, the search for 2020 was conducted in Web of Science "All Databases" during the second week of October 2020. All English language publications found under the Topic Search = ("supply chain" AND "resilien*" AND "covid*") were filtered for a minimum of 2 citations. This resulted in 12 publications for review. To check that no articles were missed, the Topic Search = ("supply chain" AND "resilien*" AND "pandemic*") was also run. This resulted in an additional article published in 2018, which did not meet citation requirements. Although the number of papers reviewed for 2020 may be underestimated, it captures the growth in publications pertaining to supply chain resilience, especially during initial analysis of the impacts of the COVID-19 pandemic on supply chain resilience. Of the 271 publications from 2020 tagged under supply chain resilience in WOS, 42 are also tagged with "covid*" (15%) and 35 are also tagged with "pandemic*" (13%). However, despite the burgeoning literature, only 12 of these publications met citation requirements and only 4 met relevancy requirements for review.

The four additional publications analyzing supply chain resilience in the context of COVID-19 extend the trends identified in earlier literature, and further highlight the gaps in current understanding and models of supply chain resilience. None of the publications take a direct approach to defining resilience, missing an opportunity for clear 4-stage temporal analysis mid-pandemic. Although all relevant publications discuss at least two stages of resilience, there is overwhelming focus on the absorb and recover stage (see Table 22.4).

Although the publications span multiple sectors and locations, the analyses lack clear insights into modeling resilient supply chains and miss the opportunity to provide metrics in real time. Of the two publications that use case studies, one is unrelated to a pandemic disruption (Ivanov and Dolgui 2020b), and one analyzes lightning equipment in China by proposing comparisons of performance quantifications without a direct connection to supply chain resilience, but rather indirectly through inventory, customer, financial and lead-time performance levels (Ivanov 2020a). Another publication uses set lists, but minimally analyzes hypothetical disruptions, while also measuring supply chain performance indicators such as cost and service level (Ivanov 2020b). The author neither tests the model in the context of a real-world disaster, nor offers a true model for supply chain resilience analytics. However, the focus on "Intertwined Supply Networks" does add depth to the supply chain model, and shows that unanticipated connections among healthcare, industrial, pharmaceutical and food supply chains are necessary to include in supply chain models. Overall, the clear lack of resilience metrics for supply chains apparent in the 2007–2019 literature review hold true despite the plethora of various disruption types caused by the COVID-19 pandemic.

22.4 COVID-19 Vaccine Supply Chain Resilience Needs and Challenges

Some estimates indicate that 70% of the global population will need a COVID-19 vaccine in a short timeframe, which will overwhelm the existing infrastructure and vaccine supply chain systems in place (UN 2020). Assuming that manufacturing

Table 22.5 Overview of vaccines supported by OWS or other U.S. federal government efforts (CoVPN 2020; Jackson et al. 2020; Keech et al. 2020; Sadoff et al. 2020; Sahin et al. 2020; WHO 2020a, b)

Manufacturer	Vaccine name (s)	Vaccine type	Number of doses	Notes
AstraZeneca/ University of Oxford	AZD1222 ChAdOx1-S	Recombinant vector (platform based)	2 (day 1 and 29)	• Uses chimpanzee adenovirus to deliver SARS-CoV-2 spike protein • ChAdOx1 immunogenic in older adults (i.e. target population) and can be manufactured at scale
Janssen/Johnson & Johnson	Ad26.COV2.S JNJ-78436735 Ad26COVSl	Non-replicating viral vector (platform based)	1 for lessening severity 2 (day 1 and 56)	• ENSEMBLE study • Uses Janssen's adenovirus vector to deliver SARS-CoV-2 spike protein • Promising immunogenicity and manufacturing profiles
Moderna	mRNA-1273	LNP-encapsulated mRNA (platform based)	2 (day 1 and 29)	• COVE study • mRNA encodes the SARS-CoV-2 spike protein
Novavax	NVX-CoV2373	Full length recombinant (platform based)	2 (day 1 and 22)	• SARS-CoV-2 spike protein in baculovirus expression system • Matrix-M1 adjuvant (saponin based) for thermostability (2–8 °C)
Pfizer & BioNTech	BNT162b2 BNT162b1	3 LNP-mRNAs (platform based)	2 (dose finding)	• Lipid nanoparticle-formulated mRNA with SARS-CoV-2 spike protein • Quick and scalable mRNA manufacturing and LNP formulation
Sanofi/ GlaxoSmithKline	SARS-CoV-2 biological and adjuvant formulations	Recombinant protein (platform based)	2 (day 1 and 22)	• SARS-CoV-2 spike protein in baculovirus expression system • Uses GSK established adjuvant

capacity is scaled, should a disruption in the cold chain occur, for example, spoilage on the order of billions could occur if current global vaccine spoilage rates hold true (UN 2020). Even prior to approval of a vaccine and Phase IV of the vaccine development process, clinical trials are also reliant on a working vaccine supply chain. It is therefore imperative to proactively model the COVID-19 vaccine supply chain with resilience analytics so that vaccine manufacture, distribution and inoculation can occur regardless of disruption events.

Operation Warp Speed in the U.S., for example, addresses vaccine development, manufacture and distribution, with the goal of 300 million vaccine doses delivered by January 2021 (HHS 2020b). Such initiatives include the preemptive manufacture of needles, syringes, vials, supply kits and fill-finish equipment (HHS 2020c). These consumables are being produced under Federal contract for the Strategic National Stockpile to have 400M to 700M each by the end of 2020 (Elton et al. 2020). For example, SiO_2—one of two leading glass vial manufacturers in the U.S., along with Corning—has increased production to 120 M vials per month (Elton et al. 2020). The overview of distribution and administration for Operation Warp Speed shows a linear flow of material from Contracted OWS Manufacturers to Distributors to Partner Depots and finally to Administration Sites (Pharmacy, LTC Providers, Home Health, Indian Health Services, Other Federal Entity Sites, Public Health Clinics, Hospitals, Doctor's Office, Mobile Vaccination, Mass Vaccination), including a side distribution for Ancillary Supplies/PPE to Kitting and Distributor (HHS 2020a).

Therefore, similar to other national and global efforts (e.g. COVAX), Operation Warp Speed is directly supporting vaccine efforts (HHS 2020b). The new platform vaccine technologies being developed—emerging infectious disease (EID) medical countermeasures (MCMs)—do provide economies of scale, but by the very nature of EIDs, will not provide financial rewards without private-public partnerships. Table 22.5 highlights the supply chain ecosystems supported by the U.S. Government through partnerships with manufacturers for accelerated vaccine production. Although they incorporate platform technologies which were already in place and available for quick production, they are not commercially optimized, all requiring cold chain and multiple doses (Gottlieb 2020). The number of doses implicates not only the distribution mechanisms of the supply chain, including cold chain, last mile, and associated networks, but the supply chains underpinning the manufacturing ecosystem, such as syringes, vials, and biologicals.

As implementation of Operation Warp Speed continues with increased manufacturing capacity, attention to resiliency against disruptions is necessary, not just at specific manufacturing nodes, but throughout the entirety of the associated networks, such as transportation and C2 (Golan et al. 2020). This includes anticipating how other essential vaccine supply chains will be affected, as goals for one vaccine campaign may impact all vaccine supply chains (Assi et al. 2012). And conversely, there is also the opportunity to capitalize on the large COVID-19 vaccine campaign and administer other necessary immunizations simultaneously (Toner et al. 2020). Other critical infrastructure functions must also be maintained, and security risks minimized (Gomez et al. 2020). During manufacture, some risks for OWS include cyber-attacks and biological threats. For example, as of October 8, 2020, several U.S. vaccine manufacturers and academic labs have been targets by Chinese government-linked hackers (Sutter et al. 2020).

As discussed in prior sections, the last leg of the vaccine supply chain will not only be controlled by the associated networks, but specifically largely controlled by policy makers (C2), who will implement allocation to targeted populations as well as control vaccine manufacture and supply. Beyond specific populations deemed essential for national security (e.g. military, etc.), understanding which populations are at the highest risk is also essential to an inoculation program and targeted supply chain—adding value to the "value chain" (Linkov et al. 2020). Populations at higher risk include those with more severe symptoms due to physical underlying conditions (e.g. age, weight, respiratory), but also from socioeconomic and demographic trends, including homeless populations. In the U.S., for example, the country leading the globe for both the number of confirmed COVID-19 cases and deaths, Latinx people are hospitalized at 4 times the rate of their white counterparts (Watson et al. 2020). The trend is even higher in Black, Native American, and Alaska Native people who are hospitalized at 5 times the rate of their white counterparts (Watson et al. 2020). Additionally, the transmission rate among incarcerated individuals is more than double that of the U.S. population, and within Immigration and Customs Enforcement detention centers, models show infection of 72% to 100% of individuals within 3 months of the first infection (Watson et al. 2020). This has larger implications on the population as a whole and associated networks. For example, as of April 19, 2020, up to 15.9% of all COVID-19 cases in Chicago may be attributed to Chicago's Cook County Jail (Watson et al. 2020).

Another Johns Hopkins study addresses priority groups for the vaccine response, incorporating the unequal morbidity and mortality rates across population sectors into their model, suggesting that Tier 1 include those groups (1) essential in sustaining the ongoing COVID-19 response, (2) at greatest risk of severe illness and death, and their caregivers, (3) most essential to maintaining core societal functions; and Tier 2 include those groups (1) essential to broader health provision, (2) with least access to health care, (3) needed to maintain other essential services, (4) elevated risk of infection (Toner et al. 2020). Understanding the intricacies of the last mile for targeted populations is necessary to incorporate in the vaccine supply chain model, allowing for effective targeted vaccination campaigns such as the smallpox "ring" strategy. Targeting these priority populations requires an overarching national strategy, that could potentially allocate vaccines to states on a per capita basis or hot spot basis (Toner et al. 2020). The supply chain needs to be able to respond to any ebbs and flows in disease outbreaks and/or changes in distribution policies (agile and resilient).

Also at play in public policy is the notion of "essential." Different definitions of "essential workers" throughout individual state responses may muddle a national response once a vaccine is ready for distribution. Twenty-two of the 42 states with essential worker orders differ from the federal definition given by the US Cybersecurity and Infrastructure Security Agency (CISA) (NCSL 2020). Proper public education campaigns should be coordinated to minimize last mile disruptions. Finally, there will need to be a way to track who has received a vaccine, which will be especially critical if efficacy requires two doses (Toner et al. 2020). As with any health tracking policies, health privacy issues would need to be addressed. Impacts from concurrent public health policy objectives such as social distancing must also be accounted for in vaccine supply chain models, as social distancing requirements, for example, could decrease the number of people able to queue for vaccine distribution and the amount of time and economic input required by health professionals for sterilization between patients.

Understanding who the end user is, and how to mitigate disruptions in the last mile of delivery to high-risk populations is imperative in proactively modeling and developing a resilient vaccine value chain. Even if an efficient supply chain is developed, if a disruption leaves it below optimal performance, widespread and timely distribution of the vaccine may not be achieved: a resilient vaccine supply chain model is warranted (Linkov et al. 2021).

22.5 Conclusions

In light of the current COVID-19 pandemic and the rush to bring a viable vaccine to market, ensuring an efficient mechanism is also in place for distribution to target populations in an equitable and resilient manner can only be achieved with resilience analytics in vaccine supply chain network models. Unexpected disruptions in such a large-scale effort are inevitable; using the four phase temporal approach to resilience—plan, absorb, recover, adapt—to quantitatively model all facets of the vaccine supply chain and its associated networks is missing in the current vaccine supply chain literature and needs to occur as aggressively as vaccine development. All supply (value) chains operate within system domains: physical, cyber, cognitive and social (Golan et al. 2020; Linkov et al. 2020; Mersky et al. 2020) and this must be expanded to vaccine/immunization supply chains in order to fully understand the network interactions and ultimately vaccine supply chain resilience in a quantitative manner.

As emergency use authorization (EUA) by the FDA for a COVID-19 vaccine is likely (Johns Hopkins Bloomberg School of Public Health 2020), the vaccine supply chain will also need to be efficient enough to ramp up production and logistics, while also able to be resilient in the face of likely disruptions, ensuring target populations are inoculated in a timely manner and lives saved. A national strategy that maximizes existing networks of both existing vaccine supply chains and the associated networks will be necessary. Consideration of the consequences of unequal disruptions and cascading failures on marginalized sectors of supply chains is necessary in order to support resiliency of the entire supply chain network and ensure that goals of the networks are met.

Given recent promising vaccine technologies, from the form the vaccine takes, such as needleless, dried, or ambient temperature resistant, to the types of cold chain equipment used in distribution and the last mile, it is more imperative than ever to model the larger network interactions and quantify where to invest time, energy and money to get the most value out of the COVID-19 vaccine supply chain. The supply chains underpinning the unique biopharmaceutical manufacture of vaccines to the networks ensuring safe distribution to appropriate end users must be fully modeled so that disruptions can be better understood, and the vaccine supply chain hardened in an efficient manner. Similar conclusions regarding resilience of other critical infrastructure supply chains, such as the Information and Communications Technology (ICT) and biopharmaceutical finished goods, during the COVID-19 pandemic have been reached, calling for refining supply chain risk-management approaches, mapping and standardizing detailed supply chain networks (i.e. increasing visibility into all tiers), planning for transportation bottlenecks, dual-sourcing, and holding buffer inventories (CISA 2020; Jacoby et al. 2020; Resilinc 2020).

Further building on current trends in supply chain resilience analytics modeling and prior work in the field (Golan et al. 2020; Hynes et al. 2020a; Ivanov and Dolgui 2020a; Linkov et al. 2021; Mersky et al. 2020; Trump and Linkov 2020; Linkov et al. 2018) in the context of the vaccine supply chain and disruptions discussed in this chapter, we recommend the following in the development of the supply chain underpinning the COVID-19 vaccine immunization program:

1. Incorporation of the definition of supply chain resilience across all vaccine supply chain models and sectors is necessary to make resilience management more efficient. We recommend adoption of the standard four-stage definition of resilience provided by NAS—plan, absorb, recover, adapt;
2. Consideration of different types of disruptions within the vaccine supply chain resilience models—especially assessing system recovery from unknown disruptions and systemic threats—is necessary to expand the scope that supply chain resilience management is able to quantify;
3. Consideration of the tiered approach to modeling, ranging from simple metrics to advanced network models, is necessary for understanding which quantification method to apply to the analytic need;
4. Consideration of the vaccine supply chain within the broader context of other networks that constitute value generation (e.g., command and control, cyber, transportation) and overall increased visibility and mapping is necessary for quantification of global network interactions and more robust vaccine supply chain resilience models that accurately portray trade-offs between efficiency and resilience to avoid cascading failures and maintain existing immunization goals while also meeting new public health targets;
5. Consideration of the consequences (i.e. trade-offs) of unequal disruptions and cascading failures on marginalized sectors of supply chains is necessary in order to support resiliency of the entire vaccine supply chain network and ensure that goals of the networks are met, especially in regards to critical infrastructure.

These considerations would enable public health officials, governing agencies, pharmaceutical manufacturers, and distributors, among others, to more efficiently and effectively implement COVID-19 vaccination targets and quantitatively weigh trade-offs in supply chains. Implications of the pandemic on associated networks must be modeled in tandem with the vaccine supply chain itself using resilience analytics to ensure immunization targets are met regardless of disruptions to the supply chain.

Disclaimer: The views and opinions expressed in this article are those of the individual authors and not those of the U.S. Army or other sponsor organizations.

This chapter is based, in part, on prior published research in the special issue on "Risk and resilience in the time of the COVID-19 crisis" (Igor Linkov and Benjamin D. Trump, editors) of Springer's Journal *Environment Systems and Decisions, v40(2), 2020*.

References

Adalja AA, Watson M, Cicero A, Inglesby T (2019) Vaccine platforms: state of the field and looming challenges. Johns Hopkins Bloomberg School of Public Health, Center for Health Security. https://www.centerforhealthsecurity.org/our-work/pubs_archive/pubs-pdfs/2019/190423-OPP-platform-report.pdf

Anderson R et al (2014) Supporting immunization programs with improved vaccine cold chain information systems. In: EEE global humanitarian technology conference (GHTC 2014), San Jose, CA, pp 215–222. https://doi.org/10.1109/GHTC.2014.6970284

Arifoğlu K, Deo S, Iravani SMR (2012) Consumption externality and yield uncertainty in the influenza vaccine supply chain: interventions in demand and supply sides. Manag Sci 58 (6):1072–1091. https://doi.org/10.1287/mnsc.1110.1469

Assi T-M, Rookkapan K, Rajgopal J, Sornsrivichai V, Brown ST, Welling JS, Norman BA, Connor DL, Chen S, Slayton RB, Laosiritaworn Y, Wateska AR, Wisniewski SR, Lee BY (2012) How influenza vaccination policy may affect vaccine logistics. Vaccine 30(30):4517–4452. https://doi.org/10.1016/j.vaccine.2012.04.041

Assi T-M et al (2011) Impact of changing the measles vaccine vial size on Niger's vaccine supply chain: a computational model. BMC Public Health 11(1):425–425. https://doi.org/10.1186/1471-2458-11-425

Belongia EA, Naleway AL (2003) Smallpox vaccine: the good, the bad, and the ugly. Clin Med Res 1(2):87–92. https://doi.org/10.3121/cmr.1.2.87

Biomedical Advanced Research and Development Authority (BARDA) (2020) Influenza & emerging infectious diseases. U.S. Department of Health & Human Services. https://www.medicalcountermeasures.gov/barda/influenza-and-emerging-infectious-diseases/

Bill and Melinda Gates Foundation (Gates) (2020) Vaccine development and surveillance strategy overview. https://www.gatesfoundation.org/what-we-do/global-health/vaccine-development-and-surveillance

Brownlow K, Thornton D (2014) Strengthening immunization supply chain systems through the GAVI Alliance immunization supply chain strategy. J Pharm Policy Pract 7(S1). https://doi.org/10.1186/2052-3211-7-S1-O7

Cavalcante IM, Frazzon EM, Forcellini FA, Ivanov D (2019) A supervised machine learning approach to data-driven simulation of resilient supplier selection in digital manufacturing. Int J Inf Manag 49:86–97. https://doi.org/10.1016/j.ijinfomgt.2019.03.004

Centers for Disease Control and Prevention (CDC) (2016) History of smallpox. National Center for emerging and Zoonotic Infectious Diseases (NCEZID), Division of High-Consequence Pathogens and Pathology (DHCPP). https://www.cdc.gov/smallpox/history/history.html

Centers for Disease Control and Prevention (CDC) (2019) Vaccine storage and handling toolkit. U.S. Department of Health and Human Services. https://www.cdc.gov/vaccines/hcp/admin/storage/toolkit/storage-handling-toolkit.pdf

Chen S, Norman BA, Rajgopal J, Lee BY (2015) Passive cold devices for vaccine supply chains. Ann Oper Res 230(1):87–104. https://doi.org/10.1007/s10479-013-1502-5

Chen S, Norman BA, Rajgopal J, Assi T, Lee BY, Brown ST (2014) A planning model for the WHO-EPI vaccine distribution network in developing countries. IIE Trans 46(8):853–865. https://doi.org/10.1080/0740817x.2013.813094

Chick H, Hasija S, Nasiry J (2017) Information elicitation and influenza vaccine production. Oper Res 65(1):75–96. https://doi.org/10.1287/opre.2016.1552

Choong YYC, Tan HW, Patel DC, Choong WTN, Chen C-H, Low HY, Tan MJ, Patel CD, Chua CK (2020) The global rise of 3D printing during the COVID-19 pandemic. Nat Rev Mater 5:637–639. https://doi.org/10.1038/s41578-020-00234-3

Cogan D, Karrar K, Iyer JK (2018) Shortages, stockouts and scarcity: the issues facing the security of antibiotic supply and the role for pharmaceutical companies. Access to medicine Foundation, The Netherlands. https://accesstomedicinefoundation.org/media/uploads/downloads/5bea831e16607_Antibiotic-Shortages-Stockouts-and-Scarcity_Access-to-Medicine-Foundation_31-May-2018.pdf

Comes T, Bergtora Sandvik K, Van de Walle B (2018) Cold chains, interrupted: the use of technology and information for decisions that keep humanitarian vaccines cool. J Humanit Logist Supply Chain Manag 8(1):49–69. https://doi.org/10.1108/JHLSCM-03-2017-0006

Controlled Temperature Chain Working Group (2017) Controlled temperature chain: strategic roadmap for priority vaccines 2017–2020. World Health Organization 2017(WHO/IVB/17.20), Geneva. https://www.who.int/immunization/programmes_systems/supply_chain/ctc_strategic_roadmap_priority_vaccines.pdf?ua=1

Cooney E (2019) Inspired by breath strips, scientists break away from needing a 'cold chain' to deliver vaccines. Stat. https://www.statnews.com/2019/05/21/scientists-break-away-cold-chain-deliver-vaccines/

COVID-19 Prevention Network (CoVPN) (2020) Clinical studies. National Institute of Allergy and Infectious Diseases (NIAID), U.S. National Institutes of Health. https://coronaviruspreventionnetwork.org/understanding-clinical-studies/

Cybersecurity and Infrastructure Security Agency (CISA) (2020) Building a more resilient ICT supply chain: lessons learned during the COVID-19 pandemic. https://www.cisa.gov/publication/ict-supply-chain-lessons-learned-covid-19

Davey VJ, Glass RJ, Min HJ, Beyeler WE, Glass LM (2008) Effective, robust design of community mitigation for pandemic influenza: a systematic examination of proposed US guidance. PLoS One 3(7):e2606. https://doi.org/10.1371/journal.pone.0002606

Defense Health Agency (DHA) (2019) Cold chain management of Measles, Mumps, Rubella vaccine. Vaccine Policy and Program Development Office. https://www.health.mil/Military-Health-Topics/Health-Readiness/Immunization-Healthcare/Vaccine-Storage-and-Handling

DHL (2020) Navigating the COVID-19 environment: trends and risks facing global tech supply chains. Resilience360. https://www.resilience360.dhl.com/resilienceinsights/navigating-the-covid-19-environment-trends-and-risks-facing-global-tech-supply-chains/

Dixit R, Routroy S, Dubey SK (2019) A systematic literature review of healthcare supply chain and implications of future research. Int J Pharm Healthc Mark 13(4):405–435. https://doi.org/10.1108/ijphm-05-2018-0028

Dungu B (2020) The role of vaccine banks in resilience, response and recovery in respect of animal diseases. Rev Sci Tech (International Office of Epizootics) 39(2):543–550. https://doi.org/10.20506/rst.39.2.3105

Elton E, Duoss E, Tooker A, Spadicinni C (2020) Domestic supply chain of medical consumables needed during COVID-19 pandemic. Lawrence Livermore National Laboratory, LLNL-TR-811868. https://www.osti.gov/servlets/purl/1634295

Emergent (2018) Highlights of prescribing information: ACAM2000, (smallpox (vaccinia) vaccine, live), FDA insert. Emergent Product Development Gaithersburg Inc., Gaithersburg, MD

FedEx (2020) FedEx to transform package tracking with SenseAware ID, the latest innovation in FedEx sensor technology. https://newsroom.fedex.com/newsroom/senseaware-id/

Feng E (2020) China's economy bounces back as pandemic is brought under control. NPR. https://www.npr.org/2020/10/19/925251602/chinas-economy-bounces-back-as-pandemic-is-brought-under-control

Folegatti P et al (2020) Safety and immunogenicity of the ChAdOx1 nCoV-19 vaccine against SARS-CoV-2: a preliminary report of a phase ½, single-blind, randomized controlled trial. Lancet 396:467–478. https://doi.org/10.1016/S0140-6736(20)31604-4

Forde M (2019) Drone delivers Merck vaccines between islands with AT&T cold-chain tech. Supply Chain Dive. https://www.supplychaindive.com/news/merck-drone-pilot-cold-chain-delivery/558621/

Galazka A, Milstien J, Zaffran M (1998) Thermostability of vaccines. Geneva: World Health Organization, Global Programme for Vaccines and Immunization (WHO/GPV/98.07). https://apps.who.int/iris/bitstream/handle/10665/64980/WHO_GPV_98.07.pdf?sequence=1

Golan MS, Jernegan LH, Linkov I (2020) Trends and applications of resilience analytics in supply chain modeling: systematic literature review in the context of the COVID-19 pandemic. Environ Syst Decis 40(2):222–243. https://doi.org/10.1007/s10669-020-09777-w

Gomez M, Garcia S, Rajtmajer S, Grady C, Mejia A (2020) Fragility of a multilayer network of intranational supply chains. Appl Netw Sci 5(71). https://doi.org/10.1007/s41109-020-00310-1

Gottlieb S (2020) COVID-19 & a responsive Rx supply chain. The Hill Webinar sponsored by HDA, Healthcare Distribution Alliance, moderated by Steve Clemons, 27 Oct 2020

Graham B (2020) Rapid COVID-19 vaccine development. Science (American Association for the Advancement of Science) 368(6494):945–946. https://doi.org/10.1126/science.abb8923

Gunn T (2020) How the cold chain could prove vital in fight to tackle the coronavirus pandemic. NS healthcare. https://www.ns-healthcare.com/analysis/cold-chain-coronavirus-vaccine/

Gurvich V, Hussain A (2020) In and beyond COVID-19: US academic pharmaceutical science and engineering community must engage to meet critical national needs. AAPS PharmSciTech 21(5):153–153. https://doi.org/10.1208/s12249-020-01718-9

Haidari LA, Wahl B, Brown ST, Privor-Dumm L, Wallman-Stokes C, Gorham K, Connor DL, Wateska AR, Schreiber B, Dicko H, Jaillard P, Avella M, Lee BY (2015) One size does not fit all: the impact of primary vaccine container size on vaccine distribution and delivery. Vaccine 33(28):3242–3247. https://doi.org/10.1016/j.vaccine.2015.04.018

Hansen KRN, Grunow M (2015) Modelling ramp-up curves to reflect learning: improving capacity planning in secondary pharmaceutical production. Int J Prod Res 53(18):5399–5417. https://doi.org/10.1080/00207543.2014.998788

Hayes T (2019) Flu vaccines are going needleless: scientists are developing a needle-free flu vaccine patch that's less painful for patients, and more convenient for health care workers. Healthcare Packaging. https://www.healthcarepackaging.com/markets/pharmaceutical/news/13702019/flu-vaccines-are-going-needleless

Hayes T (2018) Congress Asks FDA to investigate heparin supply: conflicting data on America's heparin supply has raised concerns that a shortage could lead to adulterated versions entering the market. Healthcare Packaging. https://www.healthcarepackaging.com/markets/pharmaceutical/news/13294396/congress-asks-fda-to-investigate-heparin-supply

Healthcare Distribution Alliance (HDA) Research Foundation (2019) 90th edition HDA factbook: the facts, figures and trends in healthcare (2019–2020). HDA Research Foundation, Arlington, VA. ISBN 978-0-9995125-5-5

Hobbs JE (2020) Food supply chains during the COVID-19 pandemic. Can J Agric Econ 68:171–176. https://doi.org/10.1111/cjag.12237

Hoek R (2020) Research opportunities for a more resilient post-COVID-19 supply chain—closing the gap between research findings and industry practice. Int J Oper Prod Manag 40(4):341–355. https://doi.org/10.1108/IJOPM-03-2020-0165

Hoybraten D (2014) Why global health needs the private sector. Devex. https://www.devex.com/news/why-global-health-needs-the-private-sector-84805

Hovav S, Herbon A (2017) Prioritizing high-risk sub-groups in a multi-manufacturer vaccine distribution program. Int J Logist Manag 28(2):311–331. https://doi.org/10.1108/IJLM-12-2015-0227

Hubbard B (2020) Once a COVID-19 vaccine is discovered, the hard part begins. Fortune. https://fortune.com/2020/09/17/covid-vaccine-distribution-cold-chain/

Humphreys G (2011) Vaccination: rattling the supply chain. Bull World Health Organ 89(5):324–325. https://doi.org/10.2471/BLT.11.030511

Hynes W, Trump BD, Love P, Linkov I (2020a) Bouncing forward: A Resilience Approach to dealing with COVID-19 and future systemic shocks. Environ Syst Decis 40(2):174–184. https://doi.org/10.1007/s10669-020-09776-x

Hynes W, Trump BD, Love P, Kirman A, Galaitsi SE, Ramos G, Linkov I (2020b) Resilient financial systems can soften the next global financial crisis. Challenge, ahead-of-print. https://doi.org/10.1080/05775132.2020.1822660

Iqbal R, Lorenson T (2016) Production economics for vaccines. Bill and Melinda Gates Foundation. https://docs.gatesfoundation.org/Documents/Production_Economics_Vaccines_2016.pdf

Ivanov D (2020a) Predicting the impacts of epidemic outbreaks on global supply chains: a simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case. Transp Res Part E 136. https://doi.org/10.1016/j.tre.2020.101922

Ivanov D (2020b) Viable supply chain model: integrating agility, resilience and sustainability perspectives—lessons from and thinking beyond the COVID-19 pandemic. Ann Oper Res. https://doi.org/10.1007/s10479-020-03640-6

Ivanov D, Dolgui A (2020a) Viability of intertwined supply networks: extending the supply chain resilience angles towards survivability. A position paper motivated by COVID-19 outbreak. Int J Prod Res 58(10):2904–2915. https://doi.org/10.1080/00207543.2020.1750727

Ivanov D, Dolgui A (2020b) A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0. Prod Plan Control. https://doi.org/10.1080/09537287.2020.1768450

Jackson LA et al (2020) An mRNA Vaccine against SARS-CoV-2—preliminary report. N Engl J Med. https://doi.org/10.1056/NEJMoa2022483

Jacoby R, Heim M, Preda CF (2020) The first 90 days: US biopharmaceutical finished goods supply chain response to COVID-19. Deloitte & HDA Research Foundation. https://www.hda.org/resources/the-first-90-days

Johns Hopkins Bloomberg School of Public Health (2020) What exactly is emergency use authorization, how does it work, and can we trust it? Could we see EUAs for COVID-19 vaccines? COVID-19: School of Public Health Expert Insights. https://www.jhsph.edu/covid-19/articles/what-is-emergency-use-authorization.html

Keech C et al (2020) Phase 1–2 trial of a SARS-CoV-2 recombinant spike protein nanoparticle vaccine. N Engl J Med. https://doi.org/10.1056/NEJMoa2026920

Khalili SM, Jolai F, Torabi SA (2017) Integrated production–distribution planning in two-echelon systems: a resilience view. Int J Prod Res 55(4):1040–1064. https://doi.org/10.1080/00207543.2016.1213446

Kumru O, Joshi S, Smith D, Middaugh C, Prusik T, Volkin D (2014) Vaccine instability in the cold chain: mechanisms, analysis and formulation strategies. Biologicals 42(5):237–259. https://doi.org/10.1016/j.biologicals.2014.05.007

Lal R (2020) Home gardening and urban agriculture for advancing food and nutritional security in response to the COVID-19 pandemic. Food Secur 12:871–876. https://doi.org/10.1007/s12571-020-01058-3

Lambert N, Strebel P, Orenstein W, Icenogle J, Poland G (2015) Rubella. The Lancet (British Edition) 385(9984):2297–2307. https://doi.org/10.1016/S0140-6736(14)60539-0

Larsson P (2020) COVID-19 anti-vaxxers use the same arguments from 135 years ago. The Conversation. https://theconversation.com/covid-19-anti-vaxxers-use-the-same-arguments-from-135-years-ago-145592

Lee BY et al (2012). Impact of introducing the pneumococcal and rotavirus vaccines into the routine immunization program in Niger. Am J Public Health (1971) 102(2):269–276. https://doi.org/10.2105/AJPH.2011.300218

Lee BY et al (2011a) Maintaining vaccine delivery following the introduction of the rotavirus and pneumococcal vaccines in Thailand. PLoS One 6(9):e24673–e24673. https://doi.org/10.1371/journal.pone.0024673

Lee BY et al (2011b) Replacing the measles ten-dose vaccine presentation with the single-dose presentation in Thailand. Vaccine 29(21):3811–3817. https://doi.org/10.1016/j.vaccine.2011.03.013

Lee BY, Norman BA, Assi T-M, Chen S, Bailey RG, Rajgopal J, Brown ST, Wiringa AE, Burke DS (2010) Single versus multi-dose vaccine vials: an economic computational model. Vaccine 28(32):5292–5300. https://doi-org.proxy.library.cmu.edu/10.1016/j.vaccine.2010.05.048

Leung V, Mapletoft J, Zhang A, Lee A, Vahedi F, Chew M, Szewczyk A, Jahanshahi-Anbuhi S, Ang J, Cowbrough B, Miller M, Ashkar A, Filipe C (2019) Thermal stabilization of viral vaccines in low-cost sugar films. Sci Rep 9(1):7631–7631. https://doi.org/10.1038/s41598-019-44020-w

Levner E, Hovav S, Tell H, Ptuskin A, Herbon A (2014) Using Entropy for healthcare analytics and risk management in influenza vaccination programs. In: Proceedings of the international conference on analytics driven solutions (ICAS 2014), pp 63–72

Li Z, Swann JL, Keskinocak P (2018). Value of inventory information in allocating a limited supply of influenza vaccine during a pandemic. PloS One 13(10). https://doi.org/10.1371/journal.pone.0206293

Linkov I, Trump BD, Golan M, Keisler JM (2021) Enhancing resilience in post-COVID societies: by design or by intervention? Environ Sci Technol Art ASAP. https://doi.org/10.1021/acs.est.1c00444

Linkov I, Carluccio S, Pritchard O, Bhreasail AN, Galaitsi S, Sarkis J, Keisler J (2020) The case for value chain resilience. Manag Res Rev, ahead-of-print. https://doi.org/10.1108/MRR-08-2019-0353

Linkov I et al (2018) Tiered approach to resilience assessment. Risk Anal 38(9):1772–1780. https://doi.org/10.1111/risa.12991

Malden K, Stephens S (2020) Cascading economic impacts of the COVID-19 outbreak in China. U.S.-China Economic and Security Review Commission Staff. https://www.uscc.gov/research/cascading-economic-impacts-covid-19-outbreak-china

Martin P, Gupta D, Natarajan KV (2020) Vaccine procurement contracts for developing countries. Prod Oper Manag. https://doi.org/10.1111/poms.13229

Mersky A, Golan MS, Linkov I (2020, in press) Quantitative modeling of supply chain resilience: a literature review. In: Arctic: cybersecurity and resilience. IOS Press

Military Health System (MHS) (2020) Vaccine storage and handling questions and answers. Immunization Healthcare, Storage and Handling. https://www.health.mil/Military-Health-Topics/Health-Readiness/Immunization-Healthcare/Vaccine-Storage-and-Handling/Vaccine-Storage-and-Handling-FAQs#Preparation

Moeti M, Nandy R, Berkley S, Davis S, Levine O (2017) No product, no program: the critical role of supply chains in closing the immunization gap. Vaccine 35(17):2101–2102. https://doi.org/10.1016/j.vaccine.2017.02.061

Morris P, Sweeney E (2019) Responding to disruptions in the pharmaceutical supply chain. Pharm J: R Pharm Soc Publ. https://www.pharmaceutical-journal.com/research/research-article/responding-to-disruptions-in-the-pharmaceutical-supply-chain/20206058.article

National Conference of State Legislatures (NCSL) (2020) COVID-19: essential workers in the states. https://www.ncsl.org/research/labor-and-employment/covid-19-essential-workers-in-the-states.aspx

National Institutes of Health (NIH) (2020) NIH COVID-19 supply chain response. NIH 3D Print Exchange. https://3dprint.nih.gov/collections/covid-19-response

Norman BA et al (2013) A passive cold storage device economic model to evaluate selected immunization location scenarios. Vaccine 31(45):5232–5238. https://doi.org/10.1016/j.vaccine.2013.08.079

Ouzayd F, Mansouri H, Tamir M, Chiheb R, Benhouma Z (2018) Monitoring vaccine cold chain model with coloured petri net. Int J Adv Comput Sci Appl 9(5):433–438
Patel A, D'Alessandro MM, Ireland KJ, Burel G, Wencil EB, Rasmussen SA (2017) Personal protective equipment supply chain: lessons learned from recent public health emergency responses. Healthy Secur 15(3):244–252. https://doi.org/10.1089/hs.2016.0129
Peterson BW, Damon IK, Pertowski CA, Guarnizo JT, Beigi RH, Edwards KM, Fisher MC, Frey SE, Lynfield R, Willoughby RE (2015) Clinical guidance for smallpox vaccine use in postevent vaccination program. Centers for Disease Control and Prevention 64(RR02):1–26. https://www.cdc.gov/mmwr/preview/mmwrhtml/rr6402a1.htm
Plotkin S, Robinson JM, Cunningham G, Iqbal R, Larsen S (2017) The complexity and cost of vaccine manufacturing—an overview. Vaccine 35(33):4064–4071. https://doi.org/10.1016/j.vaccine.2017.06.003
Porter ME (1985) Competitive advantage: creating and sustaining superior performance. Free Press, New York
Pujar NS, Sagar SL, Lee AL (2014) History of vaccine process development. In: Vaccine development and manufacturing. Wiley. https://doi.org/10.1002/9780470261941
Purssell E (2015) Reviewing the importance of the cold chain in the distribution of vaccines. Br J Community Nurs 20:481–486. https://doi.org/10.12968/bjcn.2015.20.10.481
Rele S (2020) COVID-19 vaccine development during pandemic: gap analysis, opportunities, and impact on future emerging infectious disease development strategies. Hum Vaccines Immunother. https://doi.org/10.1080/21645515.2020.1822136
Resilinc Eds (2020) Coronavirus webinars outline supply chain challenges. Resilinc Corporation. https://www.resilinc.com/blog/coronavirus-webinar-outlines-supply-chain-challenges/
Resilinc Corporation (2017) A new metric for measuring supply chain resiliency: an introduction to Resilinc R Score™ and its application to the high-tech industry supply chain. Resilinc and Global Supply Chain Resiliency Council. https://www.resilinc.com/white-papers-reports/
Robertson J, Franzel L, Maire D (2017) Innovations in cold chain equipment for immunization supply chains. Vaccine 35(17):2252–2259. https://doi.org/10.1016/j.vaccine.2016.11.094
Rowland MA, Swannack T, Mayo ML, Parno M, Farthing M, Dettwiller I, George G, England W, Reif M, Cegan J, Trump B, Linkov I, Lafferty B, Bridges T (2020) COVID-19 infection data encode a dynamic reproduction number in response to policy decisions with secondary wave implications. Research Square. https://doi.org/10.21203/rs.3.rs-75665/v1
Sadoff J et al (2020) Safety and immunogenicity of the Ad26.COV2.S COVID-19 vaccine candidate: interim results of a phase 1/2a, double-blind, randomized, placebo-controlled trial. medRxiv, preprint. https://doi.org/10.1101/2020.09.23.20199604
Sahin U et al (2020) COVID-19 vaccine BNT162b1 elicits human antibody and TH1T cell responses. Nature 586:594–599. https://doi.org/10.1038/s41586-020-2814-7
Salmi M, Akmal JS, Pei E, Wolff J, Jaribion A, Khajavi SH (2020) 3D printing in COVID-19: productivity estimation of the most promising open source solutions in emergency situations. Appl Sci 10(11):4004. https://doi.org/10.3390/app10114004
Sanofi (2019) Journey of vaccine: a complex manufacturing process. Vaccine Production, Sanofi. https://www.sanofi.com/en/your-health/vaccines/production
Schwarzenberg AB, Sutter KM (2020) Medical supply chains and policy options: the data challenge. Congressional Research Service. CRS IF11648
Simchi-Levi D, Simchi-Levi E(2020) We need a stress test for critical supply chains. Harv Bus Rev. https://hbr-org.cdn.ampproject.org/c/s/hbr.org/amp/2020/04/we-need-a-stress-test-for-critical-supply-chains
Setia S, Mainzer H, Washington M, Coil G, Snyder R, Weniger B (2002) Frequency and causes of vaccine wastage. Vaccine 20(7–8):1148–1156. https://doi.org/10.1016/s0264-410x(01)00433-9
Sharma A, Adhikary A, Borah SB (2020) Covid-19's impact on supply chain decisions: Strategic insights from NASDAQ 100 firms using Twitter data. J Bus Res 117:443–449. https://doi.org/10.1016/j.jbusres.2020.05.035

Smith G et al (2011a) Is there enough vaccine to eradicate measles? an integrated analysis of measles-containing vaccine supply and demand. J Infect Dis 204(suppl_1):S62–S70. https://doi.org/10.1093/infdis/jir130

Smith J, Lipsitch M, Almond JW (2011b) Vaccine production, distribution, access, and uptake. The Lancet (British Edition) 378(9789):428–438. https://doi.org/10.1016/S0140-6736(11)60478-9

Souza LPDS, Vasques JVV, Aguiar TA, Flexa R (2019) Vaccine cold chain in Brazilian health system: a logistics assessment. In: Mula J, Barbastefano R, Díaz-Madroñero M, Poler R (eds) New global perspectives on industrial engineering and management. Lecture notes in management and industrial engineering. Springer, Cham. https://doi.org/10.1007/978-3-319-93488-4_20

Stone J (2018) Fragile antibiotic supply chain causes shortages and is a national security threat. Forbes. https://www.forbes.com/sites/judystone/2018/06/01/fragile-antibiotic-supply-chain-causes-shortages-and-is-a-national-security-threat/#3a9ade01adf3

Sun T, Han H, Hudalla G, Wen Y, Pompano R, Collier J (2016) Thermal stability of self-assembled peptide vaccine materials. Acta Biomater 30:62–71. https://doi.org/10.1016/j.actbio.2015.11.019

Supply & Demand Chain Executive (SDC) (2018) Drug scandal showcases dangers in global supply chains: recent drug scandals in China highlights the risk in global supply chain after substandard vaccines were sold in the country. https://www.sdcexec.com/risk-compliance/news/21016574/drug-scandal-showcases-dangers-in-global-supply-chains

Sutter KM, Schwarzenberg AB, Sutherland MD (2020) COVID-19: China medical supply chains and broader trade issues. Congressional Research Service, CRS, R46304

Tambo E, Ngogang JY, Ning X, Xiao-Nong Z (2018) Strengthening community support, resilience programmes and interventions in infectious diseases of poverty. Eastern Mediterr Health J 24(6):598–603. http://doi.org/10.26719/2018.24.6.598

Thompson KM, Tebbens RJD (2016) Framework for optimal global vaccine stockpile design for vaccine-preventable diseases: application to measles and cholera vaccines as contrasting examples. Risk Anal 36(7):1487–1509. https://doi.org/10.1111/risa.12265

Toner E, Barnill A, Krubiner C, Bernstein J, Privor-Dumm L, Watson M, Martin E, Potter C, Hosangadi D, Connel N, Watson C, Schoch-Spana M, Veenema TG, Meyer D, Biddison ELD, Regenberg A, Inglesby T, Cicero A (2020) Interim framework for COVID-19 vaccine allocation and distribution in the United States. The Johns Hopkins Center for Health Security. https://www.centerforhealthsecurity.org/our-work/pubs_archive/pubs-pdfs/2020/200819-vaccine-allocation.pdf

Trump BD, Linkov I (2020) Risk and resilience in the time of the COVID-19 crisis. Environ Syst Decis 40(2):171–173. https://doi.org/10.1007/s10669-020-09781-0

United Nations (UN) (2020) Why optimized cold-chains could save a billion COVID vaccines. UN Environment Programme. https://www.unenvironment.org/news-and-stories/story/why-optimized-cold-chains-could-save-billion-covid-vaccines

U.S. Department of Health and Human Services (HHS) (2020a) From the factory to the frontlines: the operation warp speed strategy for distributing a COVID-19 vaccine. https://www.hhs.gov/sites/default/files/strategy-for-distributing-covid-19-vaccine.pdf

U.S. Department of Health and Human Services (HHS) (2020b) Operation warp speed. Fact sheet: explaining operation warp speed. Coronavirus (COVID-19). https://www.hhs.gov/coronavirus/explaining-operation-warp-speed/index.html

U.S. Department of Health and Human Services (HHS) (2020c) Trump administration expands manufacturing capacity with Cytiva for components of COVID-19 vaccines. https://www.hhs.gov/about/news/2020/10/13/trump-administration-expands-manufacturing-capacity-cytiva-components-covid-19-vaccines.html

U.S. Department of Health and Human Services (HHS) (2020d) Vaccine types. Vaccines. https://www.vaccines.gov/basics/types

Vaccine Europe (VE) (2016) Vaccines manufacturing. How are vaccines produced? European Federation of Pharmaceutical Industries and Associations (EFPIA). https://www.vaccineseurope.eu/about-vaccines/how-are-vaccines-produced
van Riel D, de Wit E (2020) Next-generation vaccine platforms for COVID-19. Nat Mater 19:810–812. https://doi.org/10.1038/s41563-020-0746-0
Walsh M, producer (2020) Inside the operation warp speed effort to get Americans a COVID-19 vaccine. CBS, 60 Minutes, 08 Nov 2020. https://www.cbsnews.com/news/covid-19-vaccine-distribution-60-minutes-2020-11-08/
Watson C, Warmbrod KL, Vahey RA, Cicero A, Inglesby TV, Beyrer C, Rubenstein L, Eber G, Sufrin C, Garrison-Desany H, Dayton L, Strodel R (2020) COVID-19 and the US criminal justice system: evidence for public health measures to reduce risk. The Johns Hopkins Center for Health Security. https://www.centerforhealthsecurity.org/our-work/pubs_archive/pubs-pdfs/2020/20201015-covid-19-criminal-justice-system.pdf
Wedlock P, Mitgang E, Elsheikh F, Leonard J, Bakal J, Welling J, Crawford J, Assy E, Magadzire B, Bechtel R, DePasse J, Siegmund S, Brown S, Lee B (2019) The potential effects of introducing microneedle patch vaccines into routine vaccine supply chains. Vaccine 37 (4):645–651. https://doi.org/10.1016/j.vaccine.2018.12.008
Wedlock PT, Mitgang EA, Siegmund SS, DePasse J, Bakal J, Leonard J, Welling J, Brown ST, Lee BY (2018) Dual-chamber injection device for measles-rubella vaccine: the potential impact of introducing varying sizes of the devices in 3 countries. Vaccine 36(39):5879–5885. https://doi.org/10.1016/j.vaccine.2018.08.026
Weir E, Hatch K (2004) Preventing cold chain failure: vaccine storage and handling. CMAJ: Can Med Assoc J = Journal de l'Association Medicale Canadienne, 171(9):1050. https://doi.org/10.1503/cmaj.1041565
World Health Organization (WHO) (2015) Module 2: the vaccine cold chain. https://www.who.int/immunization/documents/IIP2015_Module2.pdf
World Health Organization (WHO) (2017) PQS devices catalogue: pre-qualified equipment for the Expanded Programme on Immunization (EPI).WHO Department of Immunization, Vaccines and Biologicals-Quality, Standards and Safety. https://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/categorypage.aspx?id_cat=17
World Health Organization (WHO) (2019) Feasibility assessment of measles and rubella eradication. https://www.who.int/immunization/sage/meetings/2019/october/3_Feasibility_Assessment_of_Measles_and_Rubella_Eradication_updatedSAGE.pdf
World Health Organization (WHO) (2020a) Draft landscape of COVID-19 candidate vaccines. https://www.who.int/publications/m/item/draft-landscape-of-covid-19-candidate-vaccines
World Health Organization (WHO) (2020b) What we know about COVID-19 vaccine development: the latest on the Covid-19 global situation & vaccine development. https://www.who.int/docs/default-source/coronaviruse/risk-comms-updates/update37-vaccine-development.pdf?sfvrsn=2581e994_6
Wyeth (2004) Smallpox vaccine: dried, calf lymph type; Dryvax dried smallpox vaccine FDA insert. Wyeth Pharmaceuticals, Philadelphia. http://novaccine.com/wp-content/uploads/2014/02/Dryvax_package_insert.pdf
Yeung J (2020) The US keeps millions of chickens in secret farms to make flu vaccines. But their eggs won't work for coronavirus. CNN. https://www.cnn.com/2020/03/27/health/chicken-egg-flu-vaccine-intl-hnk-scli/index.html

Index

I. Linkov et al. (eds.), *COVID-19: Systemic Risk and Resilience*, Risk, Systems and Decisions, https://doi.org/10.1007/978-3-030-71587-8