Chapter 9
Economics During the COVID-19 Crisis: Consumer Economics and Basic Supply Chains

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Abstract The COVID-19 pandemic has other perspectives than just the epidemiological one that impacts human lives. In this chapter, we look at the economic perspective by modelling a consumer economic system with a basic supply chain and a very basic government role to create a circular economic system. People have to work at shops or workplaces to earn money to buy food or other items. These items are sold by shops who in turn buy them from workplaces. We devise multiple scenarios to compare the effects of the pandemic, measures to lessen the epidemiological effects and additional economic effects. The results show us that we can: (1) create an useful economic model in the complex ASSOCC context, (2) that from an economic perspective repeated lockdowns are more harmful than not taking any action at all, and (3) economic measures do support economic well being of the population. While it is very clear that the real world is a lot more complex than how we have modelled it, the modelling process helps us pinpoint where next steps of policy investigation, model improvement and research could be performed.

9.1 Why Read This Chapter?

In this chapter, we discuss various economic aspects of a pandemic and the COVID-19 pandemic in particular. In particular, we focus on consumer economics and a basic supply chain. This allows us to see the consequences of lockdowns and restrictions for different types of persons and how these consequences influence the behaviour and reactions to further restrictions. This perspective on the effects of a pandemic comes with its own challenges, both for the economic sub-model and the ASSOCC model as a whole. We discuss the motivation behind adding this perspective and its scenarios to the ASSOCC model. After this, we present the conceptual model and

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the chosen fundamental basis for this model. This proved to be non-trivial as we could not just an economic model to the rest of the ASSOCC framework, but had to fit the economic consequences of actions and decisions to the model. So, we started of with some very generic economic principles and fitted the specific details of the economic model around these principles.

The translation from conceptual model to the implementation in the bigger ASSOCC model, comes with its own challenges. In this chapter, we will discuss this extra dimension of complexity of using the resulting economic model as a sub-model. In order to show the influence of economics on society during the COVID-19 crisis we will look at four different economic scenario's: no pandemic, a pandemic with no measures, a pandemic with a lockdown and a pandemic with a lockdown and an economic measure that pays wages. We will discuss our results by analysing a number of key metrics and why we have chosen these specific key metrics.

9.2   Introduction and Motivation

The COVID-19 pandemic has severe direct medical consequences. A relative high number of people get hospitalised or even die after contracting COVID-19. This alone has various direct consequences on other aspects of life. For example; a deceased parent can no longer provide care for his or her children. People, and mainly governments, try to reduce or even prevent the spread of the virus with various measures, such as closing schools, restaurants and even complete lockdowns. This shows that the COVID-19 pandemic also has *indirect* effects on our societies. These indirect effects cause *second-order effects* on the society as a whole, which in turn affects the spread of the disease.

Some of the most prevalent second-order effects are the effects on the economy. Economic recessions were expected early into the pandemic. In the Netherlands, by the end of March 2020 and one month into the local pandemic, the economy was predicted to shrink by 7.7%[1] which would be a bigger recession than the banking crisis recession from 2009. While this sounds severe, only five months later it became clear that this was still a conservative estimation as the economy shrunk by 8.5%.[2] The economy of the EU as a whole has shrunk by 7.8% in November 2020 and predictions made at the time indicate that the economy will not recover very quickly.

These figures are more than just numbers: unemployment rises, people have less income and self worth, government tax income decreases whilst government expenditure on social security rises. Given these severe (long-term) effects of the pandemic on the economy, it is imperative to have a better understanding how measures regarding the pandemic affect the economy. Incorporating the economic aspect in the

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[1] https://nos.nl/artikel/2328385-cpb-vreest-diepe-recessie-economie-kan-krimpen-met-7-7-procent.html.

[2] https://nos.nl/artikel/2344026-catastrofale-krimp-van-de-nederlandse-economie-min-van-8-5-procent.html.

ASSOCC model will allow evaluation of various trade-offs between economic, social and medical consequences of government interventions. E.g. should only restaurants and pubs be closed or should all shops be closed (except for limited access to supermarkets). Complete lockdowns can provide a quicker decrease of infections, but also might have much bigger economic consequences.

Undoubtedly there are many economic effects of the COVID crisis. Many of these effects are still unknown and will only unfold in the years after the pandemic has subsided. In ASSOCC, the main actors are individuals, consumers, and their daily lives. Thus in our model we focus on the economic aspects of their daily lives. With "our economy" we focus on the consumer economics system and the directly related other agents. We will investigate the following three issues in this chapter:

1. Investigate the effect of a pandemic on the local economy.
2. Investigate the effects of measures taken by government to stop the pandemic on the economy.
3. Compare economic measures that could mitigate the negative effects stemming from the pandemic.

To investigate these issues in a structured manner we have structured the chapter as follows. We first describe the components of the economic model and their implementation in ASSOCC in Sect. 9.3. Once the fundamentals are described, we discuss various scenario's in Sect. 9.4 that help us gain insight in the three issues. Finally we show the results in Sect. 9.5 and discuss them in Sect. 9.6. In Sect. 9.7, we draw our final conclusions on the topic of modelling an economy in ASSOCC and indicate options for further work.

9.3 An Economic Model for ASSOCC

In the ASSOCC model, we are interested in the decision making and actions of individuals. Thus, an economic model for ASSOCC should be based on the behaviour of individual people. This requirement leads us in the direction of micro-economic models, with the challenge of finding an appropriate one. Interesting enough, this starts us off with a contrast when we look at the "newspaper headlines" that are supposed to inform us about the economic effects of COVID-19 in the real world. These, at least in the beginning of COVID-19, mainly reported on macro-economic effects and figures such as unemployment, GDP or bankruptcies. The beauty of ABM, in theory, is that we can easily extract such macro-economic metrics from a micro-economic ABM by measuring aggregates over groups of agents.

We also see this reflected in our brief literature review[3] when looking for feasible economic ABM models to use. Most of the found ABM literature investigates a specific type of economic model or an implementation of them and how this could

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[3]Recall that ASSOCC has been created in a crisis situation.

replicate reality. Herbert Dawid and Domenico Delli Gatti give an overview of macro-economic models in [1]. The models themselves are not validated against real world data or mechanisms, but these are supposed to be given by the economic theories. In [2], on the validation of economic ABMs, Fagiolo et al. write in their concluding remarks on page 782 that validation of economic ABM is hardly possible:

> Furthermore, validation of ABMs will never tell whether a model is a correct description of the complex, unknown and non-understandable real-world data generating process. However, in a Popperian fashion, ABM validation techniques should eventually allow researchers to understand whether a model is a bad description of it.

Thus, rather than basing our model on a complete economic agent based model we base our model on some basic economic principles underlying all micro-economic models. On the Wikipedia page for *economic system*[4] we find the following definition:

> An economic system, or economic order, is a system of production, resource allocation and distribution of goods and services within a society or a given geographic area. It includes the combination of the various institutions, agencies, entities, decision-making processes and patterns of consumption that comprise the economic structure of a given community.

Given this definition we can scope our model in the following way: *the economic model consists of the economic value transition resulting from interactions between individual agents, such as consumers, government, shops and workplaces and their resulting state.* In order for the economic model to give any insights in economic consequences of the COVID crisis it should to some extend be a closed model. I.e. neither should we constantly drain money from nor insert money into the simulation. If this would have to be done the results of a simulation would mostly depend on how these leaks would be regulated rather than a result of the interactions within the simulation. As a consequence we have to somehow *close* the economy such that money more or less gets preserved and we get better sight on how it gets redistributed. In order to achieve this we use an artificial *government* agent to serve as a buffer and a means to absorb some money while also able to create money and subsidise agents during a crisis. Governments already have this function in the real world, but we have made this explicit and simplified many aspects of this role as well. We would like to stress that we exclude macro-economic aspects in this chapter (readers that are interested in possible macro-economic systems can visit Chap. 15 on Challenges) because we would need a far larger model where all economic sectors would be represented in the right proportion. This would be too complex in times of crisis and would require also far more agents than we could at present accommodate in the simulation.

Our model is based on the simple economic model of circular flow of income [4]. This model is based on the economic relationship between individuals and businesses, as depicted in Fig. 9.1. Individuals supply labour to businesses and get an income in the form of wages in return. The business can pay the wages with the the expenditure

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[4]Wikipedia   (https://en.wikipedia.org/wiki/Economic_system   https://en.wikipedia.org/wiki/Economic__system).
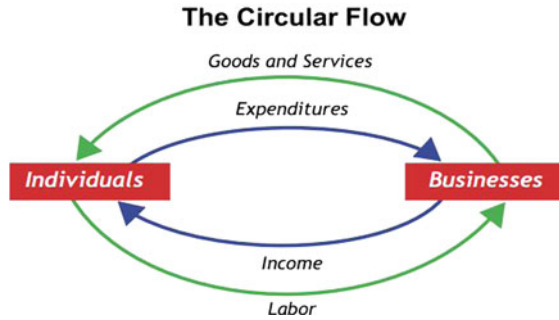
The Circular Flow

Fig. 9.1 The circular flow of income, figure from [3]

of (other) individuals at the business. The individuals get goods or services from the business in return.

The circular flow of income model is generally regarded as a macro-economic model as individuals and businesses are grouped together. To create an ABM, we don't have to group them together but can actually implement the individuals. We can use this model in the following way:

- Goods, Services and Labour are *resources* an agent (e.g. consumers, shops or workplaces) can provide to others.
- Income and expenditure is the exchange of capital between these agents in return for an action or good.

With this, we can take the idea of circular flow and use it for a conceptual micro-economic model with a grounding in accepted economic theory.

Given the basic principles of our model (based on general economic standards), we can direct our attention to making these principles actually work. Just like a machine, a working economy needs moving parts. In our case these moving parts are the agents that perform their actions, showing certain *behaviour*. In [1], Herbert Dawid and Domenico Delli Gatti make an interesting remark is made regarding behaviour and economic models:

> The design of behavioural rules determining such locally constructive actions is a crucial aspect of developing an agent-based macroeconomic model. The lack of an accepted precise common conceptional or axiomatic basis for the modeling of bounded rational behavior has raised concerns about the "wilderness of bounded rationality" (Sims (1980)), however agent-based modelers have become increasingly aware of this issue providing different foundations for their approaches to model individual behavior.

In the ASSOCC model, the foundation for agents is based on *needs* as explained in Chap. 2 and made concrete in 3. To fulfil some of their needs, agents perform actions, like acquiring food to eat and live, for which the agents need capital to be able to execute them. Agents also want to have some capital in reserve so they can survive for a while if for some reason they no longer have any income. This enables us to reuse principles of the ASSOCC framework that are already in place: the homeostatic model that is used to model the various needs of agents (see Sect. 2.3.5). The minimum reserve of capital is the threshold, income increases the homeostatic
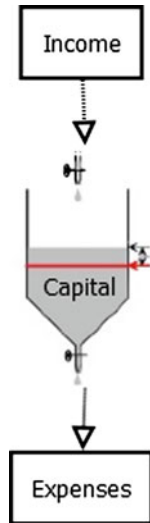
Fig. 9.2 Homeostatic model for capital based on [5]

level and the expenditure drains it, as depicted in Fig. 9.2. The use of the homeostatic model reflects that the amount of capital available to an individual should be more or less balanced over time. To provide for basic needs such as food and shelter agents have continuous expenses that drain the capital tank over time. Income fills the tank but might not come in the same frequency or time as it linked to different actions. If the tank is drained to a level below the threshold the agent will have a salient *need* to refill the tank. In general it holds that when the level of capital decreases the need to gain capital increases. This is very similar to the continuous use of energy by the body during the day and the replenishment of energy by eating food and drinking water at certain times a day.

9.3.1 From Fundamentals to a Real Economic System

In this section we describe how the fundamentals can be put to work in our model. Agents can have jobs to perform work at shops, workplaces, hospitals, universities, etc. to make money and provide labour in return. When they are not working, they can go to shops and spend money to satisfy their needs. In our model we assume that not everybody is able to work, like students and retired people. They receive scholarships and pensions from government in the form of monetary benefits or a subsidy. We also assume healthcare and education are paid for with taxes, so the universities and hospitals do not make money from the services they provide to agents, but get their income from the government. The tax component is modelled by creating the government as an agent in the ASSOCC model. The government makes money by levying taxes on things like sales and spends money by paying agents working in education and healthcare, next to paying the pensions and scholarships. These
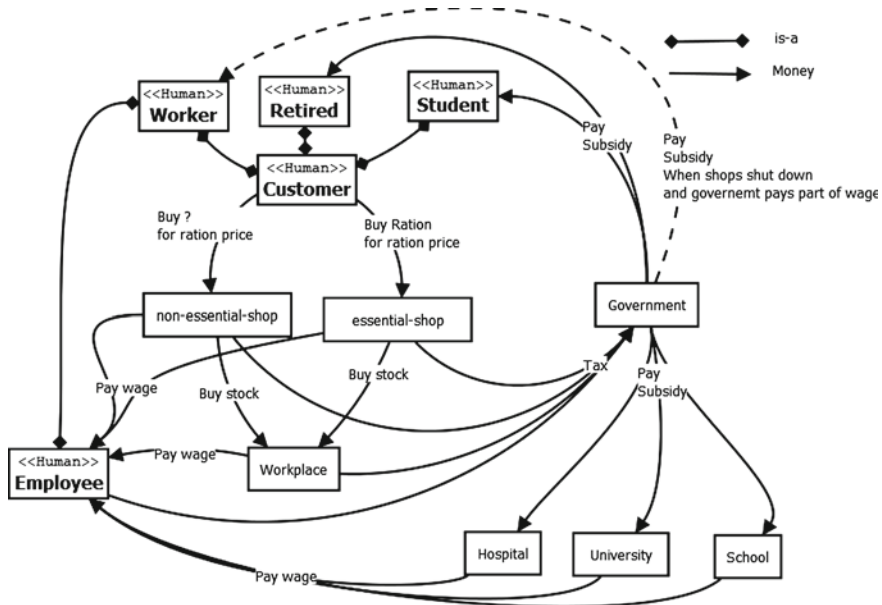
Fig. 9.3 Flow of capital

assumption are based on western European societies, which is also the perspective on how other things work in the model.

A generalised model is depicted in Fig. 9.3. In this diagram we see three of the four ASSOCC agent types. Children are not considered to be active economic parties. They can go the shops and restaurants, but the money they spend comes from their parents. The *worker* agents function as employees in the supply side of the model, while they are customers in the demand side of the model. Since students and retired agents do not work or produce resources for others they are only customers in this model. For the sake of simplicity, we have chosen not to model a full supply chain of goods and manufacturing. Thus, workplaces include all kinds of businesses, ranging from factories to wholesalers and from consultants to banks. Workplaces do not buy goods but create goods to supply to the shops when workers perform work at workplaces. Workplaces are generic and offer generic goods for all our shops, both essential and non-essential. Each of the entities (rectangles) in the model contains its own capital tank. Thus a shop has capital which gets replenished by customers paying for goods or services, while the capital diminishes by having to buy products from suppliers, pay tax and having to pay wages to employees (including the owner of the shop). Hospitals, schools and universities are not paid by their "customers", but get money from government that comes from the tax income as mentioned before. This income from government is completely used for paying wages of employees of these institutions. Using this very simple model affords us to concentrate on the micro-economic aspects related to a basic supply chain of both labour and goods.
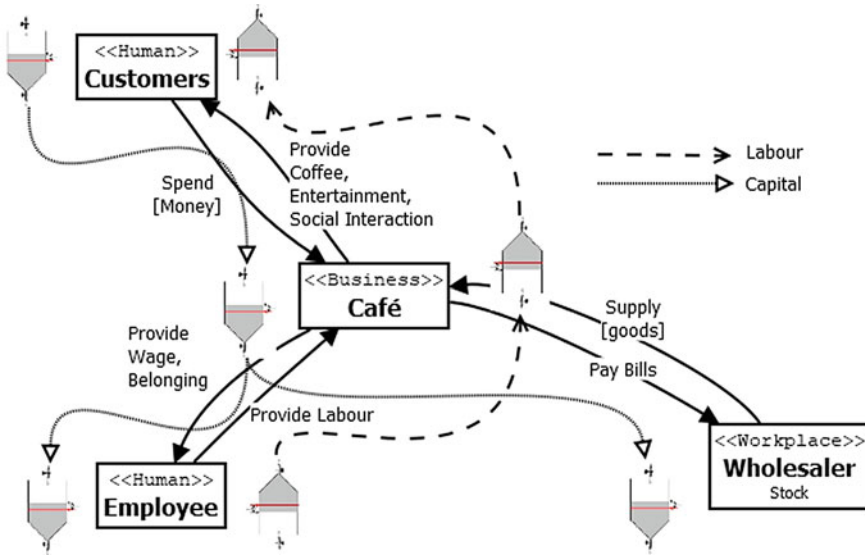
Fig. 9.4 A visualisation of the café example

Example—Home Town Café

We use one example to illustrate the combination of a homeostatic model and a circular economy. In this example, capital is exchanged for other things.

Imagine a café in your local town or city. This café offers various services to customers, from just a quick cup of coffee on-the-go to a complete experience with really comfy seating and great service. As a customer, you receive these goods, services and experiences that fulfil one or more of your needs in exchange for capital. In exchange you pay the café and drain capital from your *capital tank*, which in turn fills the café's capital tank. At the same time, an employee (or owner) at the café provides a service to you, labour. For this, the café pays the employee a wage and drains its own capital tank to fill the capital tank of the employee.

In turn, all these employees of the café are also customers at other places, just like you. This way, the capital, or money, keeps circulating from one person, shop or agent to another and back again. Thus "Money makes the world go round" while you visit a café and enjoy your drink.

An illustration of the scenario is shown in Fig. 9.4, where also the role of workplaces (e.g. wholesalers) is included to buy and sell stock for the café to operate.

9.3.2   Needs and Economic Activity

The ASSOCC model is based on needs of people to guide their behaviour as explained in Chaps. 2 and 3. The economic activities that people perform are also driven by the needs system. The most basic needs related to economic factors are *food-safety*, *financial-survival* and *Luxury*. As discussed in Sect. 3.7.4, working satisfies the financial-survival need as people gain money (wages) by performing this action. Food-safety and luxury are satisfiable by buying goods at essential and non-essential shops. Buying at non-essential-shops also gives a sense of *belonging*. On the other hand *risk-avoidance*, *financial-stability*, *autonomy* and *financial-survival* satisfaction are decreased by buying things at (non-)essential-shops.

The model consists of four daily time-steps and has a morning-afternoon-evening-night cycle. During this cycle, different actions are available to agents depending on the time of day. This also means that different needs are satisfiable at different points in time. The situations described in the previous paragraph are valid in the mornings. In the afternoon, evening and night, people can also *relax* at a non-essential-shop. At night people, can not gain *belonging* at a non-essential-shop as they are closed. More details on satisfiable needs can be found in Appendix C.

The needs model uses stochastic distributions in assigning the strength of needs to our population, different agents value the same things things differently. Some agents will value financial-safety highly, while other really like to live in luxury without having concerns for their financial well being. Thus, our agents will make different decision regarding how and when they will spend their money, even when they are in the same situation.

Note that it would be possible to use the combined needs of an agent as a kind of utility function that would allow for the agent to determine how much it would be willing to pay for resources or services. This could then lead to market mechanisms that drive prices for each resource. However, although prices for certain resources changed during the COVID crisis, this is not the focus of this chapter. Most of the consumer products that we are considering in this chapter are food and luxury things like clothes, etc. The changes in prices of these products have not changed significant enough to influence the whole economic condition of the society. This is influenced far more by the lockdowns and closures of shops, restaurants and pubs. Thus we decided to keep the model simple and not incorporate the market making mechanisms.

9.3.3   Supply Chain

One economic relevant aspect that got impacted by COVID-19 is the supply chain. Initially, Chinese factories closed down which led to shortages of goods in Europe. How a supply chain works is simple in concept but in reality these chains can be very complex. To get from a raw resource to a final product can take hundreds of steps in the complete supply chain.

In our model, we have taken a very basic but practical view on this part of the economic system. *Workplaces* produce goods, primarily for the local market. The goods from a workplace are bought by *essential shops* and *non-essential shops* to replenish their stocks. If shops run out of stock they can no longer provide services or goods to people. If workplaces should run out of goods, shops can no longer buy new stock. Thus, if workplaces have no workers producing goods (e.g. due to lockdowns or many workers being ill), people can no longer buy food once reserves run out. This gives us the basic supply chain of workers → workplaces → shops → consumers. This minimal supply chain gives us at least an impression how shops can suffer from both a lack of customers and a lack of supply due to the crisis. Also, if workplaces have excess production that isn't bought locally they can sell this outside the system, but mostly for a reduced price.

9.4   Economic Scenarios

With the economic model in place, we can develop various scenarios to analyse the consequences of a pandemic and measures from the economic perspective. In this section, we will discuss the various scenarios, their goals and how these are configured within the ASSOCC model.

For the analysis of the economic effects we have devised four scenarios:

1. No pandemic, life is as usual and provides a baseline for analysis.
2. A pandemic without any measures taken.
3. A pandemic with a lockdown to deal with the epidemiological consequences.
4. A pandemic with a lockdown and an unemployment subsidy from the government.

In the following sections we first discuss the key metrics that we use for the analysis. Then we will go into more detail to see what the different scenario's entail and set expectations on what we expect to see with regard to the key metrics.

9.4.1   Metrics for Analysis

For each of the scenarios, we can measure general things such as *infections* and the *Quality of Life*.[5] For the economic perspective, we can look at additional effects, such as the *financial position* of people and shops. This financial position entails to "can agents and shops buy everything that they need?". We can check this through the amount of people being in *poverty* or *shops being out of capital*. To measure possible positive effects we also look at the *capital of shops* and *capital of people* as it might increase more during a pandemic for certain groups. Do note that there are no ways for people or businesses to go into debt in our simulation.

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[5]See Sect. 3.12 for the description of Quality of Life.

If we look at the whole economic system, we can use the *velocity of money* to give us an idea of the health of the current economy. With the velocity of money we look at how often money is changing ownership in an economy. The velocity of money is defined (as in [6]) as follows:

$$V_T = \frac{V T_T}{M_T}$$

where in a certain time-frame T, V_T is the velocity of money, $V T_T$ is the total value of transactions and M_T is the amount of money in circulation. In this definition, we ignore economic phenomena such as inflation, because we have no inflation in our model due to the relatively short time scale of our simulations. Generally, an economy is seen as more healthy if V_T is higher. I.e. if there are more economic interactions preformed with the same overall amount of money.

We expect to see the velocity of money decreasing when a lockdown is in effect. People have less options to spend money while the amount of capital in the system stays effectively the same. It will be interesting to see how the velocity changes once a lockdown is lifted or the pandemic dies out.

Other aggregate metrics that are of interest are *goods produced in the system* and the *government capital reserve*. the government is the only agent that can go into debt, which is a reflection of reality in the model.

This gives us the following list of key metrics:

1. Number of infections.
2. Quality of Life.
3. Capital of people.
4. People in poverty.
5. Capital of shops.
6. Shops and workplaces out of capital.
7. Velocity of money.
8. Goods produced in the system.
9. Government capital.

9.4.2 Calibrating a Baseline

With our economic scenarios, we want to gain more insight in the effect of a pandemic and related measures on the economy. We do this by comparing our key metrics between different scenarios. This requires a stable and *realistic* baseline scenario. With realistic we basically mean that the baseline should adhere to basic observations from the real world as it functions in every day life, such as:

- People always have enough money to survive.
- Shops, workplaces, schools, etc. have enough money to pay wages.
- Shops are supplied with enough goods to operate.

- The government operates roughly break-even.
- Shops and workplaces don't have a monopoly and cause other shops or workplaces to go bankrupt.
- People go to their workplace to work.

Thus, in short, we assume there is a kind of balance in the economy that lets every agent survive even when they can have temporary shortages or slowly accumulate some capital. An other important aspect is the choice not to implement a real market making mechanic with supply and demand influencing prices; in principle, all prices are static.

This does leave us with a challenge: *money sinks*. These sinks are formed by agents, e.g. people or shops, that have more capital flowing in than out by being good at saving money or making profit. Shops have no motivation to spend this extra money and as a result hoard the money, basically extracting it from the system. People are driven by needs, thus, agents that have a high need to own money prioritise *not* spending money over spending money. Conversely, we see that some people really like to spend money, basically living payday to payday and are considered to be in poverty often.

During our balancing work, we learned that the sinks can drain most of the money from the system and lead to a complete stand-still in economic activity, simply because there is no money available to exchange. We have been calibrating the settings (see the next section for the particular settings) of the baseline scenario to avoid this effect of these sinks. We have also implemented three mechanics to reduce the impact of these sinks as it was both unfeasible and unrealistic to remove them completely:

1. The government is able to go into debt, thus providing infinite money with subsidies.
2. If people have more money, they spend more money at shops.
3. Workplaces can sell excess production outside the local system and add extra capital to the system.

Each of these mechanisms is realistic as they represent mechanics from the real world, where economies are never completely closed or the amount of available money being static. Mechanism one replicates the real world of government bonds and loans to acquire money to spend. Number two also reflects what happens in the real world where we generally see that people spend more in shops when they have more money available. The main motivation for mechanism three is that we saw that the workplaces seemed to be particularly sensitive to the sinks hoarding all the money as they were "at the end of the line" regarding the capital chain. With this mechanism they can have a small constant influx of money which makes them less dependent on the behaviour of the sinks in the system. In the real world, we can compare this to transactions with a neighbouring town or country which are not part of the local economy.

9.4.3 Generic Scenario Settings

With the assumptions and mechanics explained we can take a further look at our general settings for all the economic scenario's. All the settings in Table 9.1 that are related to prices and production are the result from the calibration based on the discussion in the previous section. As such the prices have no resemblance to prices in the real world. Basically we only model a part of the costs and expenses that people normally have and thus the wages and daily expenses are much tighter related in our model than in real life. The calibration is also heavily influenced by the choice of culture and household profile, see Chap. 8 for more on different cultures. We chose the United Kingdom for this as this profile has been thoroughly investigated with the work on the Oxford model, see Sect. 12.3 for more information. The UK profile comes with around 1000 agents in the simulation that nicely divide over the different age groups and households. The other generic settings for the scenarios found in Table 9.1 follow from these principles.

9.4.4 Scenario Descriptions and Expectations

Now that we have explained the fundamentals of all the scenario's we can describe the four scenarios and what they aim to show.

1. Baseline—no pandemic or infections

    a. This scenario is the baseline scenario for our analysis: no pandemic and life goes on as normal.
    b. Economy is stable and continues to operate within certain bounds.

2. Infections, no measures

    a. Infections occur.
    b. No measures from the government.
    c. Agents do not adapt to the pandemic.
    d. We expect a bad epidemiological situation.
    e. We expect the economy to stagnate when many agents get ill and/or die.

3. Infections, lockdown

    a. Infections occur
    b. Government enforces the a "10-5 lockdown". A strong lockdown is enforced once 10% of the population is infected and lasts until the numbers are down to 5% infected. This results in closing workplaces and non-essential-shops, among others. Workers get paid by workplaces, that still have money, if they can't work due to lockdown.
    c. The lockdown cuts most cycles of income, as depicted in Fig. 9.5.

Table 9.1 General settings for the economy scenario's

Description	Value
Culture profile	United Kingdom
Household profile	United Kingdom
Population size	~1000 people
Population distribution	28% children
	10% students
	38% workers
	24% retired
Workplaces	23 workplaces
Essential-shops	9 essential-shops
Non-essential-shops	9 non-essential-shops
Income	Worker wages: 12.5 per tick worked
	Retired pensions: 3.5 per tick
	Student scholarship: 3 per tick
Essential-shop rations base price	2.8
Non-essential-shop rations base price	4
Max stock at shop	500
Unit price of goods from workplace	2.9
Value modifier of exported surplus workplace goods	10% of price (= 0.29 per good sold)
Tax	Workers: 42%
	Essential-shops: 76%
	Non-essential-shops: 85%
	Workplaces: 60%
Starting capital	Workers: 60 retired: 50 students: 40
Goods produced per "work performed"	12
Productivity at home	50%
Percent of a wage paid by government	80%

    d. We expect agents that continue to have an income to get richer during the lockdown as they can't spend it on things they want.
    e. Agents without income as well as closed shops and workplaces might go bankrupt.
    f. Once a lockdown is lifted we expect a massive shopping spree as people have saved up money and want to satisfy their needs.

4. Infections, lockdown and wage subsidy

    a. Same as scenario 3.
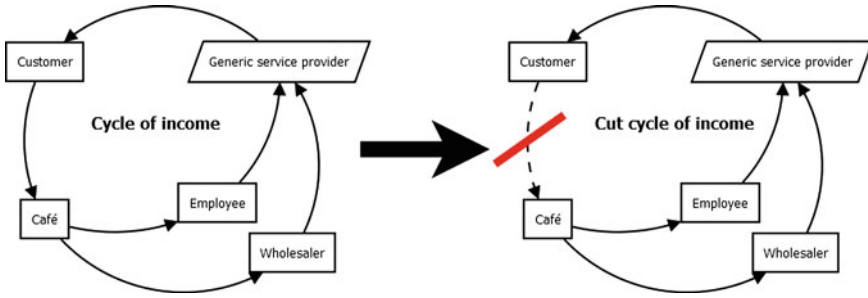   b. Government pays 80% of the wages for the workers of closed shops and workplaces once they are unable to.

Fig. 9.5   The cycle of income cut by a lockdown

  c. We expect less shops to go bankrupt and possibly quicker recovery after the crisis finishes.
  d. We expect a bigger shopping spree after a lockdown as more people will continue to have an income without the options to spend it.

9.5   Results

We will present the results of the four scenarios by discussing the key metrics as defined in Sect. 9.4.1 for each scenario. All the scenarios have been run nine times to minimise any influence of some incidental values of stochastic parameters on the overall results. Where appropriate, we also analyse the variance between runs with standard deviations or min/max run values, this will be represented in our graphs as areas around the smoothed lines. We have used the same 9 seeds for each scenario, this way we have identical starting conditions in all four scenarios. The runs lasted for 420 ticks, which is equal to 105 days or 15 weeks. Figures 9.6 through 9.25 display the graphs of the key metrics over time in our runs of the simulation. These graphs are a subset of all the graphs that we created and have been selected as they are deemed to be the most informative. Because the results can best be understood when we compare them between the four scenarios, we present the results ordered on the key metrics rather than per scenario. We will first give the brief results of the four scenarios and discuss the results in more depth in Sect. 9.6.

9.5.1   Number of Infections

1. **Baseline**
   In Fig. 9.6, we can see the flat line representing zero infections (as it should be) based on the scenario definition.
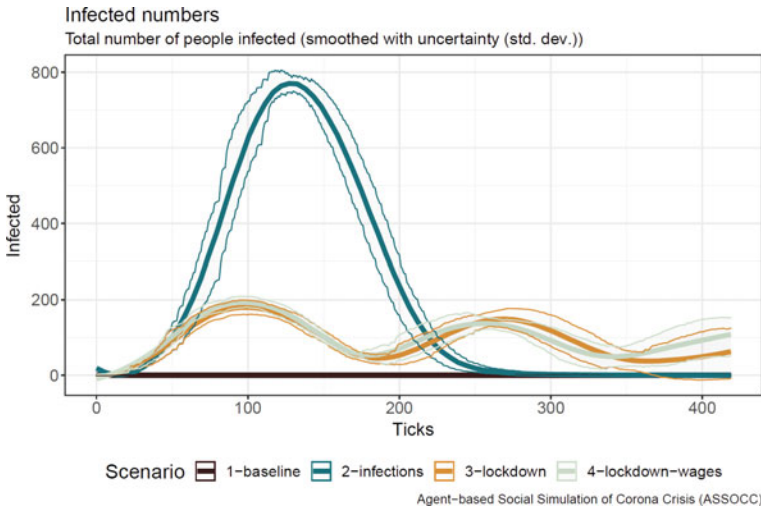
Infected numbers
Total number of people infected (smoothed with uncertainty (std. dev.))

Fig. 9.6 Number of infected in the four scenario's

2. **Infections—no measures**
   We see a steep rise in infections after the first infections occur. Once everyone is infected and has progressed to either being immune or dead, the infections steeply drop. We see the assumption that people are immune after surviving an infection clearly expressed in this line as no reinfections occur.
3. **Infections—lockdown**
   Compared to the no-lockdown scenario, we see that the first spike in infections is about $\frac{1}{4}$th lower. But on the other hand we see a wave pattern in the number of infections. This is due to the repeated lockdowns that are in effect when the the number of infections rises and are lifted when the number is low enough.
4. **Infections—lockdown and subsidy**
   We see the same wave pattern as in the lockdown scenario. The biggest difference is that after the first lockdown it seems that the infection phases are a bit shorter.

9.5.2   Quality of Life

1. **Baseline**
   In Fig. 9.7, the QoL indicator stays very stable and high throughout the whole simulation indicating that most agents can get a satisfaction level overall of around 80% in normal life. Also, the difference between people with the highest and the lowest QoL stays stable.
2. **Infections—no measures**
   We see a major decrease in QoL during the peak of the amount of infections.

Quality of life
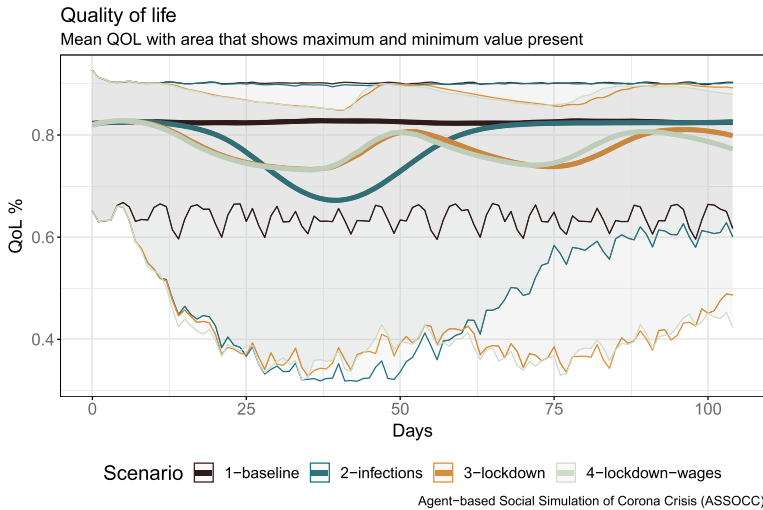Mean QOL with area that shows maximum and minimum value present

Fig. 9.7 Quality of life

During this period the difference between people's QoL increases a lot as well: the highest QoL level doesn't decrease at all while the lowest levels goes down from 0.65% to 0.35%. After the infections the QoL slowly returns to the same level as before the pandemic.

3. **Infections—lockdown**
   The quality of life during a lockdown is lower than in the baseline scenario. We also see the average QoL decreasing earlier than in the no-lockdown scenario. The lowest point of the average QoL during a lockdown is not as low as during the no-lockdown scenario, but the QoL of the people with the lowest QoL is roughly the same as in the no-lockdown scenario. We also see that the people with the highest QoL are experiencing a lower QoL compared to both the baseline and the no-lockdown scenario's. This shows that everyone is impacted by the lockdown, while in the no-lockdown scenario some people are not affected in their QoL.

4. **Infections—lockdown and subsidy**
   The QoL matches the lockdown scenario both in min and max and in the average. We also see shorter lockdown periods reflected in the QoL graph.

9.5.3 Capital of People

1. **Baseline**
   In the graphs in Figs. 9.8, 9.10 and 9.11 we see that the baseline scenario is stable. At most, we see that workers (Fig. 9.11) get steadily richer.
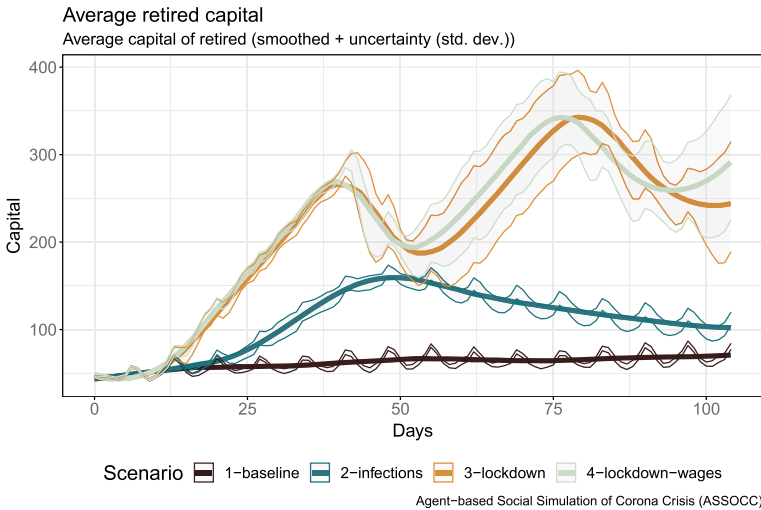
Average retired capital
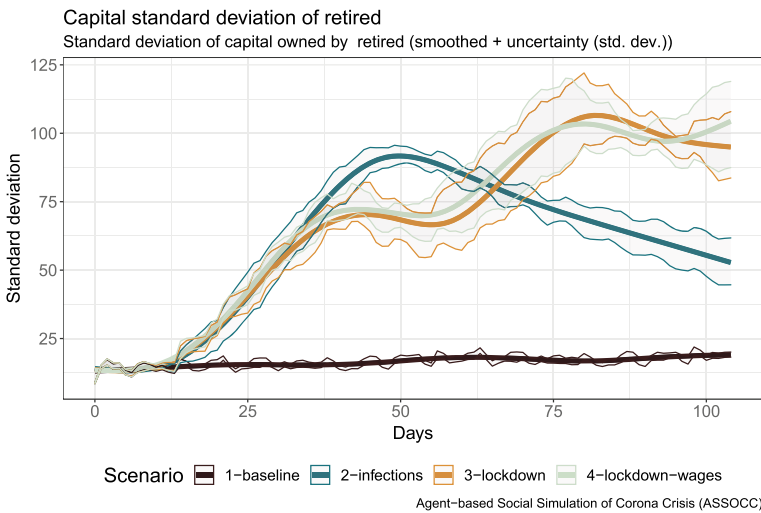Average capital of retired (smoothed + uncertainty (std. dev.))

Fig. 9.8 Average retired capital

Capital standard deviation of retired
Standard deviation of capital owned by retired (smoothed + uncertainty (std. dev.))

Fig. 9.9 The standard deviation of the retired's capital

2. **Infections—no measures**
   Compared to the baseline scenario we see that during the infection period people
   get richer on average. This is due to loss of options to spend money. If you are
   sick in the hospital, or at home, you can not go out to do shopping and spend
   your money. As retired and students have a steady income this effect is very
   visible in these groups, as seen in Figs. 9.8 and 9.10. We also see the inequality
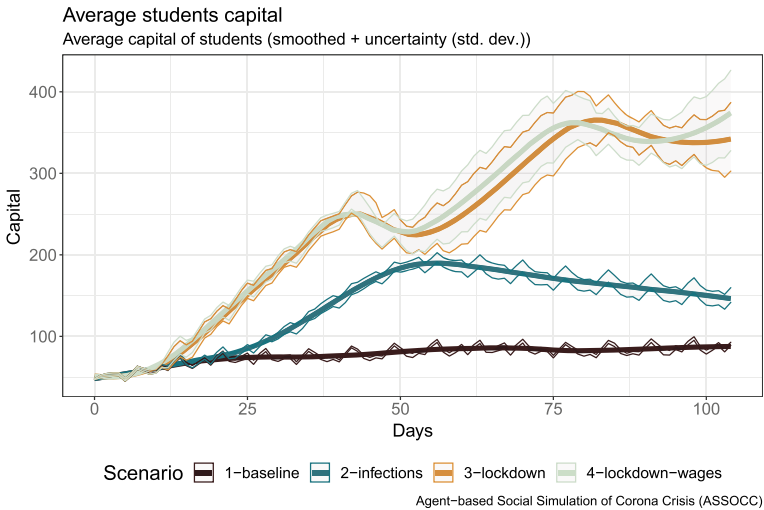   in the society increase where some agents get richer while others don't. This is
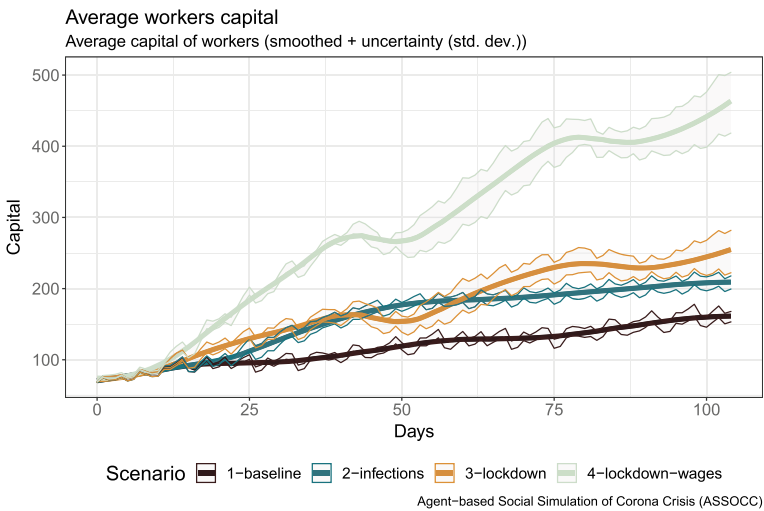
Average students capital

Average capital of students (smoothed + uncertainty (std. dev.))

Agent−based Social Simulation of Corona Crisis (ASSOCC)

Fig. 9.10   Average student capital

Average workers capital

Average capital of workers (smoothed + uncertainty (std. dev.))

Agent−based Social Simulation of Corona Crisis (ASSOCC)

Fig. 9.11   Average worker capital

especially prevalent within the group of retired people, as shown in Fig. 9.9. In this figure we see the increase of the standard deviation during the infection period and then slowly going back to the same levels as before the pandemic.

3. **Infections—lockdown**
   In this scenario we see a clear effect of the lockdowns in the same sort of way as the pandemic has in the infection scenario. People can no longer exchange their money for various needs as non-essential shops are closed, despite their income
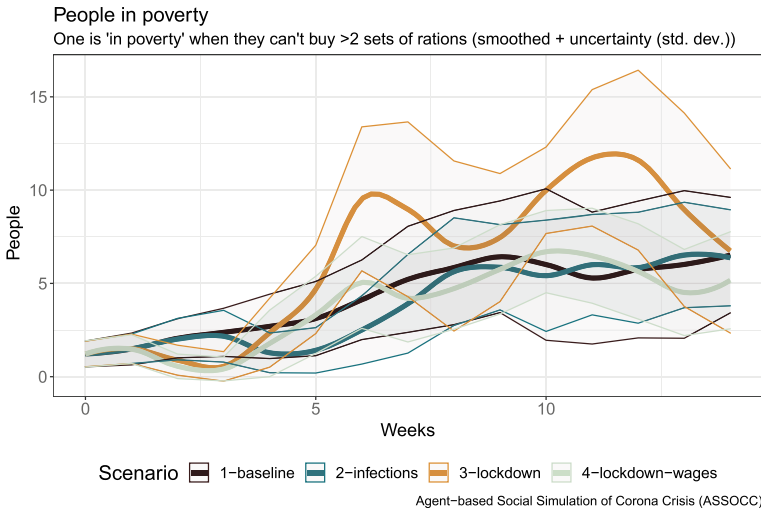
Fig. 9.12 Poverty of people

remaining the same for retired and students. For workers we see the same effect, but being less strong.

After the lockdowns we see a sudden decrease in capital. This reflects that people, when the non-essential shops open again, spend their money to satisfy their needs that they couldn't before.

4. **Infections—lockdown and subsidy**

For both retired and students this scenario mimics the lockdown scenario. This is as expected as we have not changed anything for these groups. We do see a big change for the workers. The average capital develops in the same wave pattern, but the amount of capital gained is a lot higher when compared to the lockdown scenario. This is a clear effect of the government subsidy for workplaces and shops that can no longer pay the wages of workers themselves.

9.5.4 People in Poverty

1. **Baseline**

In Fig. 9.12, during the first $\frac{2}{3}$ of the simulation, we see that the amount of people in poverty slowly rises to ~0.5% of the population. This is due to the fact that all agents of the same type start with the same amount of capital. This leads to agents that have an above average need for luxury to spend more money and balancing themselves around the poverty line. This stabilises after some time due to the influence of their other needs.
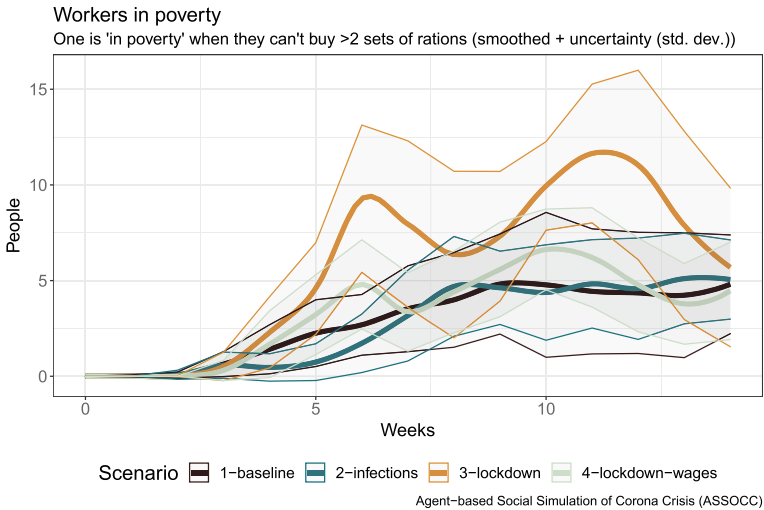
Workers in poverty
One is 'in poverty' when they can't buy >2 sets of rations (smoothed + uncertainty (std. dev.))

Scenario ▬ 1–baseline ▬ 2–infections ▬ 3–lockdown ▬ 4–lockdown–wages

Agent–based Social Simulation of Corona Crisis (ASSOCC)

Fig. 9.13 Poverty of workers

Subsidized in poverty
One is 'in poverty' when they can't buy >2 sets of rations (smoothed + uncertainty (std. dev.))

Scenario ▬ 1–baseline ▬ 2–infections ▬ 3–lockdown ▬ 4–lockdown–wages

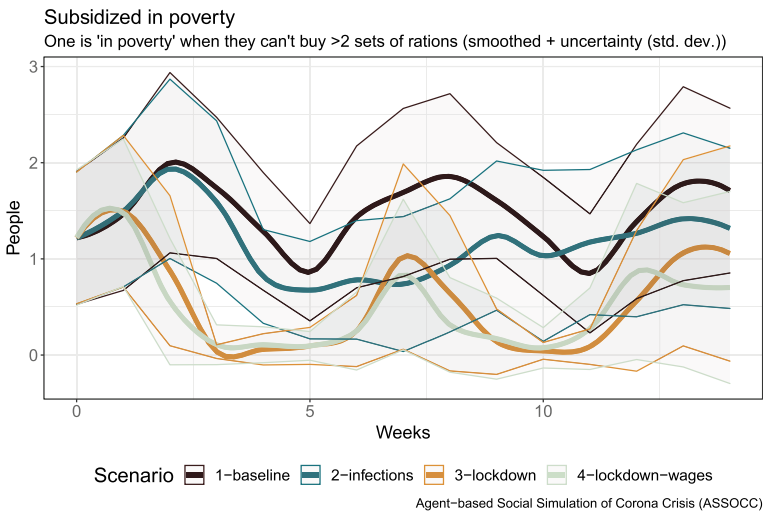Agent–based Social Simulation of Corona Crisis (ASSOCC)

Fig. 9.14 Poverty of subsidized (students and retired)

2. **Infections—no measures**
   Poverty develops comparable to the baseline scenario to ∼0.5% of the population. We do see a difference during the peak of the amount of infections where the poverty is going down or staying stable.
3. **Infections—lockdown**
   During the lockdown period we see more workers in poverty compared to the baseline and no-lockdown scenario's, but actually less students and retired people
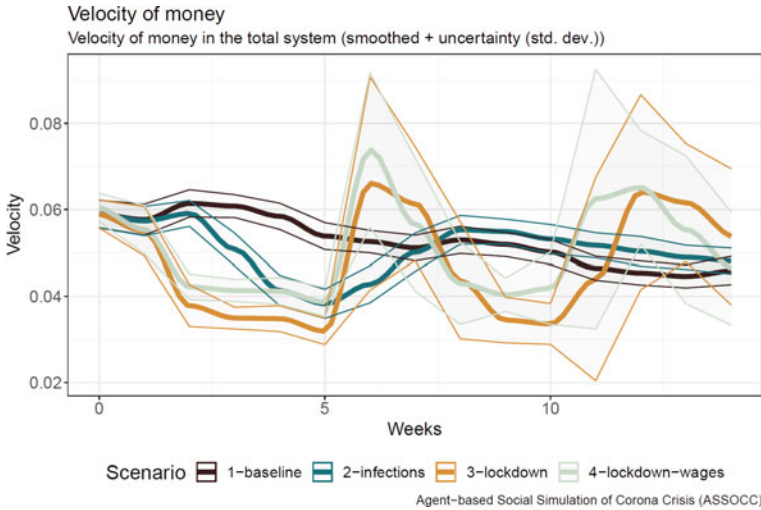
Fig. 9.15 Velocity of money

in poverty (Fig. 9.13). We see roughly twice as many people in poverty *right after the first lockdown is lifted* compared to the baseline scenario. The amount of people in poverty decreases a bit after that and seems to go back to baseline levels. During and after the 2nd lockdown we see even more people in poverty.

4. **Infections—lockdown and subsidy**
   Compared to the lockdown scenario we see the same dynamic in poverty, but being a lot more damped (Fig. 9.14). Where the lockdown scenario has roughly 1% in poverty during the shopping spree after the first lockdown, we have roughly 0.5% in poverty in this scenario. With this number the amount of people in poverty is roughly at the same level as in the baseline scenario.

9.5.5 Velocity of Money

1. **Baseline**
   In Fig. 9.15, we see the velocity of money slowly decline during the run from ~0.06 to ~0.05.
2. **Infections—no measures**
   The velocity of money seems to have the inverse trend of the infection rate. When the infections go up, the velocity goes down and the decrease peaks at ~30% of the baseline velocity. After the pandemic the velocity of money restores itself to the level of the baseline and continues with the baseline trend.
3. **Infections—lockdown**
   The velocity of money seems to have a direct relationship with the lockdowns. The

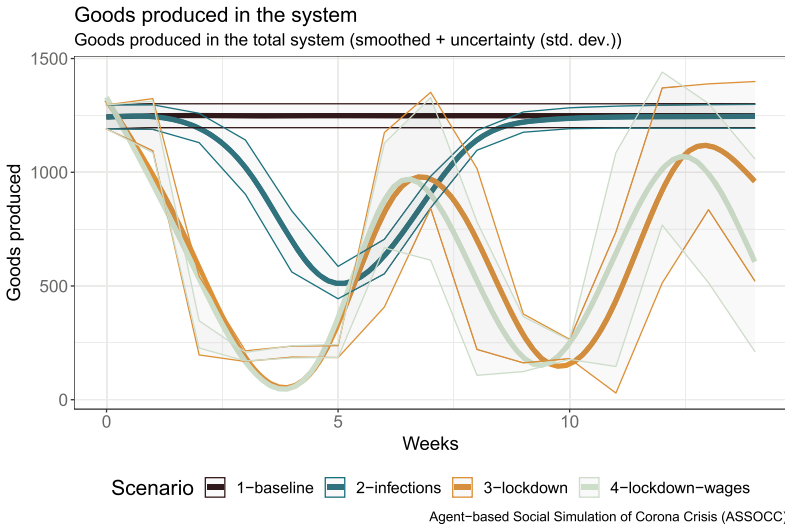Goods produced in the system

Fig. 9.16 Goods produced in the system per week

velocity instantly goes down at the beginning of a lockdown and stays relatively constant throughout the lockdown, this in contrast to the clear peak in the no-lockdown scenario. The level is lower than the lowest velocity during the no-lockdown scenario, roughly at ∼50% of the baseline scenario velocity. Once a lockdown is lifted we see a sudden increase in the velocity, roughly up to ∼135% of the baseline velocity, but the increase quickly declines after that. The next lockdown comes into effect before the velocity has stabilised. During the 2nd lockdown the velocity stabilises at the same level as the first lockdown, followed by the same sudden increase. We do see a less sudden change in during the 2nd lockdown, which might be explained by the different timings of the follow up lockdowns of the various runs.

4. **Infections—lockdown and subsidy**
   The velocity has the same trend as the lockdown scenario but stays about 15% higher during the lockdown period. With this it is at same velocity as the no-lockdown scenario is at its lowest. Also, the peaks after the lockdown is higher compared to the no-wage-subsidy lockdown scenario.

9.5.6 Goods Produced and Stock in the System

1. **Baseline**
   The goods production stays stable as seen in Fig. 9.16. In Fig. 9.17 we see that the stock for non-essential shops stays stable. This also holds for essential shops.
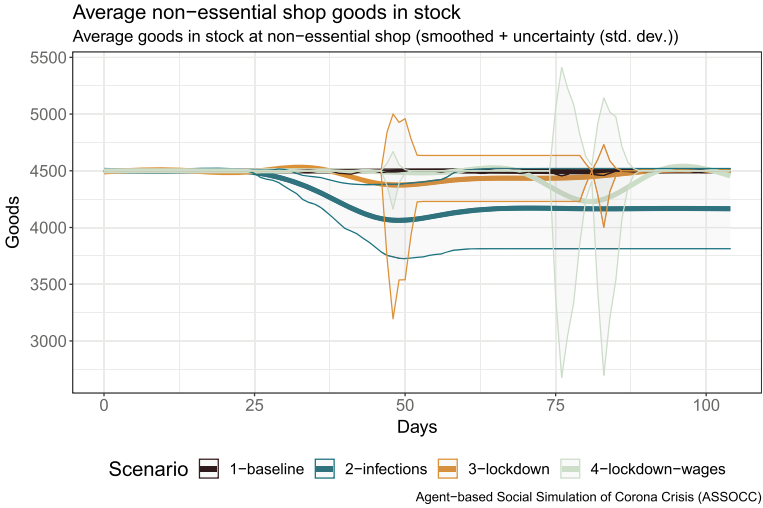
Average non−essential shop goods in stock
Average goods in stock at non−essential shop (smoothed + uncertainty (std. dev.))

Fig. 9.17 Non-essential shops goods in stock

Average workplace goods in stock
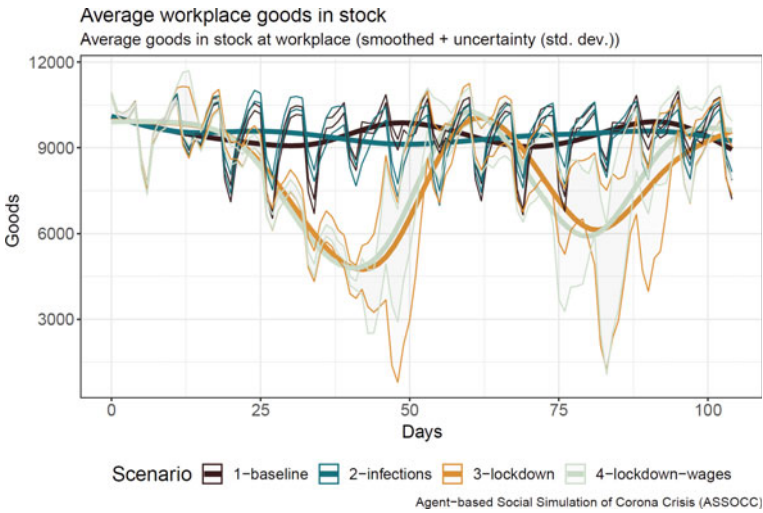Average goods in stock at workplace (smoothed + uncertainty (std. dev.))

Fig. 9.18 Workplaces in stock

In Fig. 9.18 we can see the weekly cycle of people shopping in the weekends. As they shop more in the weekends, the workplaces need to supply more goods from their warehouses. In the days after the weekend the reserves in the warehouses of the workplaces is replenished.

2. **Infections—no measures**

This graph is very comparable to the velocity of money: production goes own ~40% during infection period, but is restored to pre-infection numbers after that.

We do see that one some non-essential shops did not survive the pandemic in Fig. 9.17 as they no longer restock and cause the total stock to go down. The pandemic seems to have no real impact on the amount of stored goods at workplaces, indicating that the amount of sold goods is roughly the same as the decrease in production.

3. **Infections—lockdown**

The production is heavily influenced by the lockdowns. People work from home and have less productivity when working from home, thus reducing the production. In combination with all the people getting sick it goes down to about 25% of the normal production. In Fig. 9.18 we see that in some scenario's the average stock of workplaces almost reaching 0. This most likely means that some warehouses actually have no stock left and can not supply the shops.

This explains the sudden decrease in stock in Fig. 9.17 for some runs around day 50: workplaces can not supply then new stock, so they run out of their own stock. The timing of this spike around day 50 also coincides with the lifting of lockdown and the sudden increase of sales. Once the lockdown is lifted we see that production is quickly restored to the baseline level of production. The warehouses of the workplaces need some time to be replenished, but the shops quickly go back to healthy levels of stock.

4. **Infections—lockdown and subsidy**

We see no difference in the production of goods compared to the lockdown scenario, other than the earlier mentioned stretching of the waves. For the level of stocks for non-essential shops we the amount of sales increasing around days 75–80, thus also the amount of stocks declining for a few days.

9.5.7 Capital of Shops

1. **Baseline**

In Figs. 9.19, 9.20 and 9.21, we see that shops and workplaces are doing good on average and make decent profit. The amount of capital keeps rising as the shops and workplaces have no other options than to use this capital other than pay their workers, pay taxes and buy goods. They have no options to invest or otherwise use their capital.

2. **Infections—no measures**

Both essential and non-essential shops start on the same trajectory as the baseline scenario. During the infection phase the trajectory of the essential shops becomes a bit steeper: the shops make more profit. This new trajectory remains for the rest of the simulation, thus the essential shops continue making more profit than in the the baseline scenario. This can be explained by the fact that people have more capital on average in the infection scenario. As they have more capital, they spend more money at the shops, increasing the profit of the shops. The non-essential shops get hit during the infection phase and see their available capital going down.
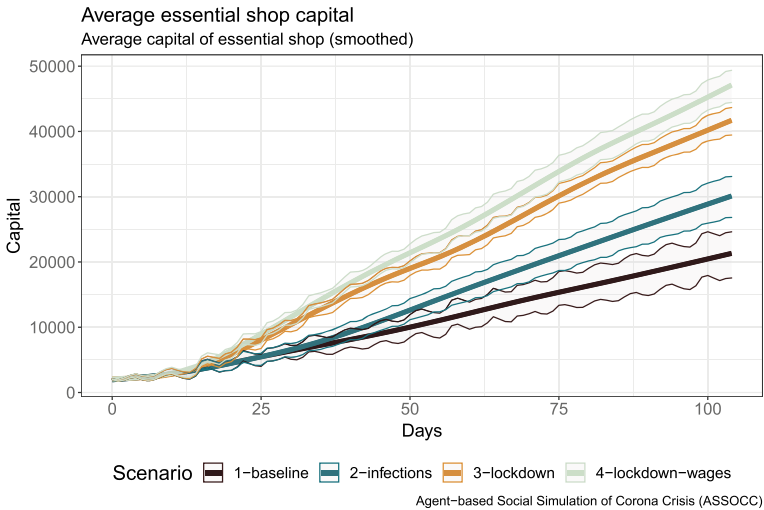
Average essential shop capital
Average capital of essential shop (smoothed)

Fig. 9.19 Essential shops capital

Average non−essential shop capital
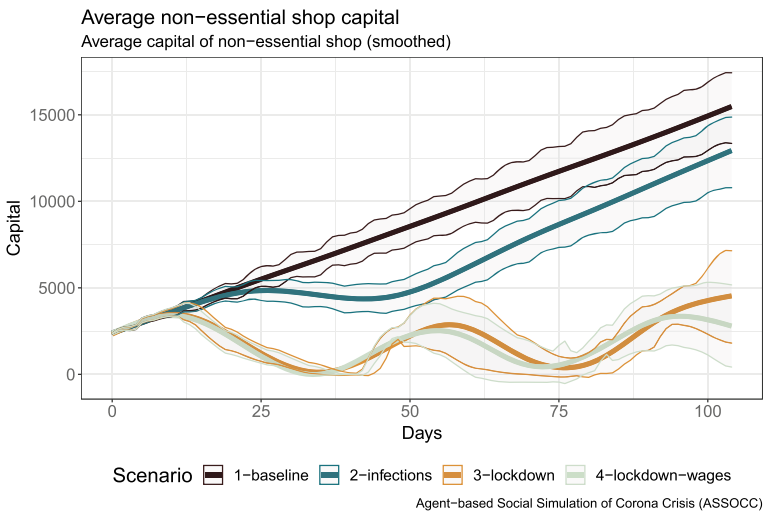Average capital of non−essential shop (smoothed)

Fig. 9.20 Non-essential shops capital

This is due to the fact that agents try to shop less to minimise risk of infection and satisfy a minimal need for luxury.

3. **Infections—lockdown**
   Essential shops stay open and make more profit than the baseline and no-lockdown scenario. Non-essential shops are closed and lose money as they continue to pay wages to their employees. Once the lockdown is lifted they suddenly have an immense amount of sales as people have money saved up and have a need to buy
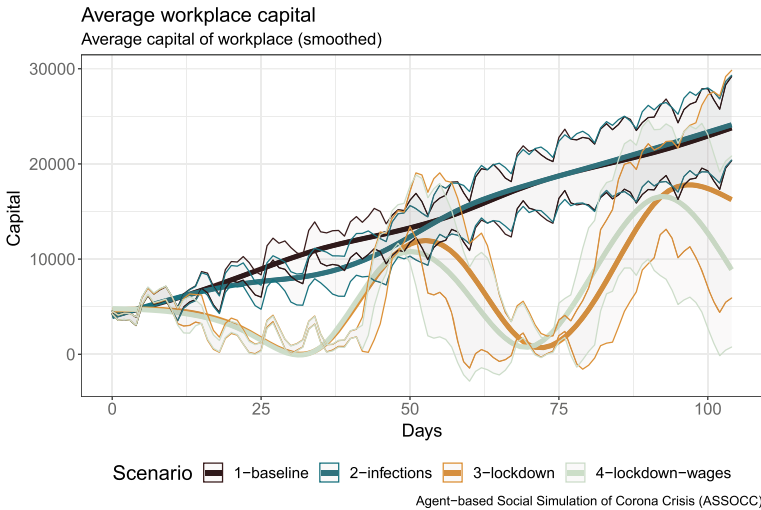
Fig. 9.21 Workplaces capital

things from the shops. This pattern repeats itself over the next lockdowns, but the variation in the amount of capital that they have increases a lot with more lockdowns.

For the workplaces we roughly see the same as they produce a lot less during lockdowns but still pay their workers. But where the non-essential shops don't seem to fully recover after a lockdown, the workplaces do seem to do this. This can be explained by the sudden higher demand and the better margins when selling locally vs selling globally.

4. **Infections—lockdown and subsidy**

We see almost no difference other than the essential shops doing even better than in the lockdown scenario. The non-essential shops behave the same as in the lockdown scenario as they need to page wages until they can't.

9.5.8   Shops and Workplaces Out of Capital

1. **Baseline**

In Figs. 9.23 and 9.24 we see that non-essential shops and workplaces do not run out of capital Essential shops seem to be having a harder time as on average ∼0.5 of them run out of capital as seen in Fig. 9.22. These figures are using weekly averages but when we look at day numbers we see that during the weekends shops always make enough money to build up some capital. We see a big difference, up to 3 times in amount of essential-shops out of capital, between the average
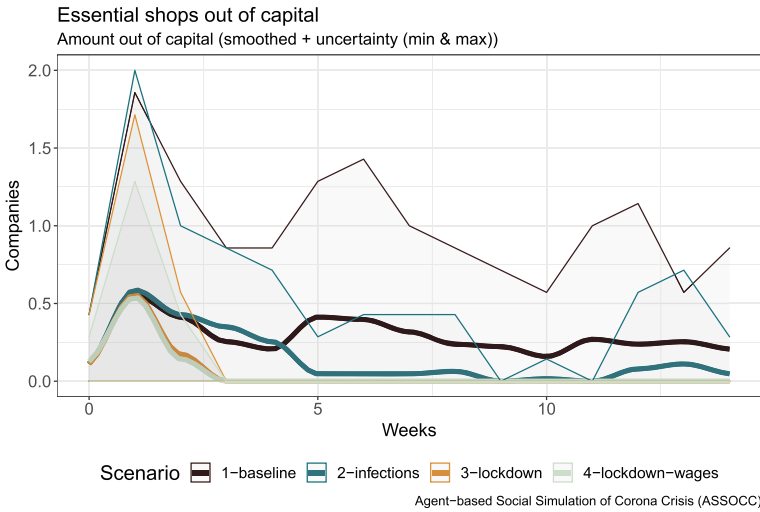
Essential shops out of capital
Amount out of capital (smoothed + uncertainty (min & max))

Fig. 9.22 Essential shops out of capital

Non−essential shops out of capital
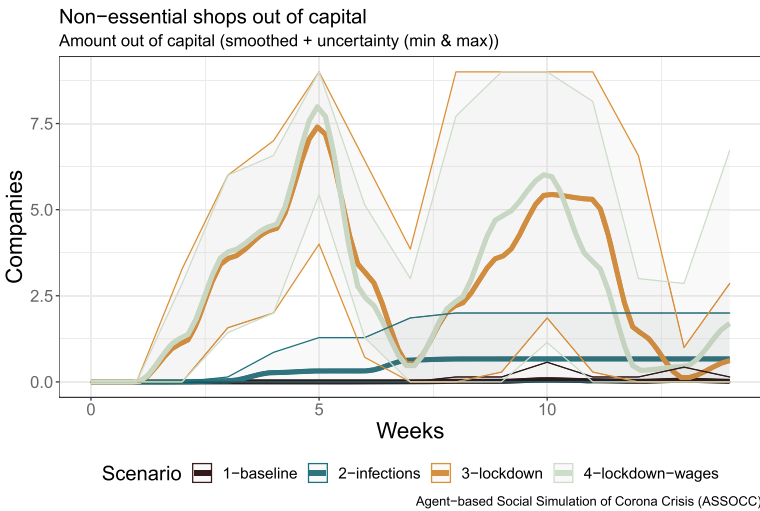Amount out of capital (smoothed + uncertainty (min & max))

Fig. 9.23 Non-essential shops out of capital

and the maximum amount of essential shops out of capital. We also saw a high standard deviation, thus there seems to be a high variance in this metric between runs.

2. **Infections—no measures**
   The trends we see here are comparable to the capital situation in the previous section. The essential shops are doing better than in the baseline scenario, having less shops being out of capital. The non-essential shops are a bit different as by
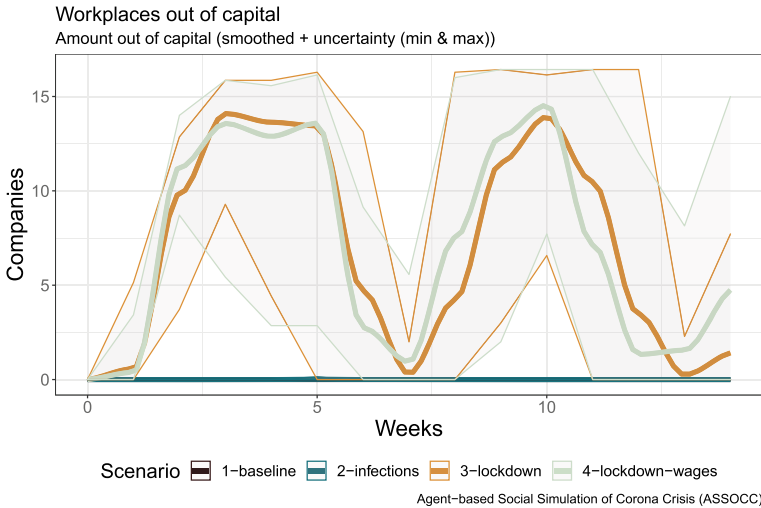
Workplaces out of capital
Amount out of capital (smoothed + uncertainty (min & max))

Scenario ■ 1−baseline ■ 2−infections ■ 3−lockdown ■ 4−lockdown−wages

Agent−based Social Simulation of Corona Crisis (ASSOCC)

Fig. 9.24 Workplaces out of capital

the end of the infection phase one or two shops are permanently out of capital and remain closed.

3. **Infections—lockdown**
   Essential shops are booming and none of them run out of capital during or after the lockdowns. As said the non-essential shops have a harder time during the lockdown as most of them (we have 9 in total, see Table 9.1) run out of capital by then end of the lockdown. It also shows in Fig. 9.23 that on average the 2nd lockdown has roughly the same effect, but the "max cases" line shows that in some runs we have a lot more non-essential shops out of capital. Some non-essential shops didn't have enough reserve to survive the lockdown and remain closed after the lockdowns.

4. **Infections—lockdown and subsidy**
   We see the same behaviour as in the lockdown scenario for both the shops and the workplaces.

9.5.9 Government Capital

1. **Baseline**
   In Fig. 9.25, we see that the government is operating with a small deficit and is slowly losing money.

2. **Infections—no measures**
   During the infection phase the government income decreased, but after this it stabilises again and seems to slowly increase.
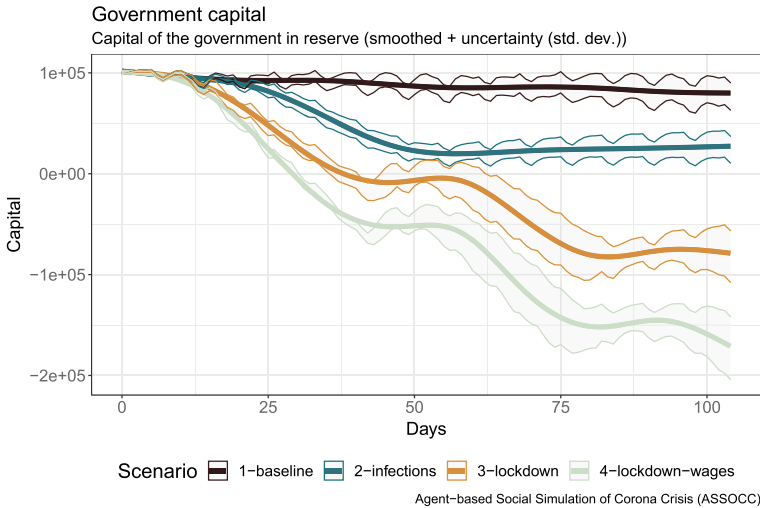
Government capital
Capital of the government in reserve (smoothed + uncertainty (std. dev.))

Fig. 9.25 Government capital in the four scenario's

3. **Infections—lockdown**
   During the lockdown the government is running with a bigger deficit than during the no-lockdown scenario. After the lockdown it is recovering a bit, but before it has time to show a clear trend the next lockdown is enacted. At the end of the 2nd lockdown we see the same pattern of slowly recovering but going going down again as another lockdown is enacted.

4. **Infections—lockdown and subsidy**
   The government capital has the same dynamic as in the lockdown scenario where we see a big deficit during the lockdowns. The only difference is that deficit is bigger than the deficit during the lockdown periods. At the end of the simulation the difference between the baseline the lockdown + wages scenario is about 3.5 times bigger than between the baseline and the no-lockdown scenario.

9.6   Discussion

Now that we have discussed the separate metrics we can look at the overall picture of our scenario's.

The first result is the baseline scenario itself. This is a functioning economic system that continues to function during the simulation runs. Workers work, receive salary, spend this to buy food, shops use the money to buy new stocks from workplaces and workplaces pay wages to workers that work. The expected behaviour of sinks and avid spenders is especially visible with the workers where the standard deviation in average worker capital continues to increase during the simulation. It is interesting

to note that we do not see real change in the QoL indicator during the simulation, indicating that the increase of the amount of people in poverty does not affect their QoL.

In the second scenario people get infected while no measures are taken. Here we see the biggest effect of people who are sick. They don't work, hence the decrease in production, and they stay home unless they need to buy food to survive. When people are sick they continue to get paid their wage or allowance but don't spend it. This results in people having more money after the infection phase and, as a result, spend more money in shops. This explains shops making more profit after a pandemic in our model.

We do see that this the reserves people have build up go down over time. If we would run this simulation for a longer period we expect the profit to return to the baseline trajectory. One big effect that we see is that some non-essential shops don't have enough capital in reserve to survive the infection phase. They remain open and pay full wages but sell less goods, thus running at a deficit. This results in a situation where some of them end up spending all their capital on paying wages without being able to buy new stock to sell after the pandemic, and going out of business completely. Also, the government takes a one-time hit due to loss of taxes while expenses stay the same. In reality this could be more severe as we would expect that the government needs to spend more money on healthcare during and after a pandemic, for example on vaccines.

The third scenario has multiple lockdowns, as we can clearly see in Fig. 9.6. This causes a wave pattern in most of our metrics. The wave seems to be getting weaker for every next wave, most likely as the amount of people that are immune is increased with every resurgence of the virus.

These lockdowns create an interesting economic dynamic. People can not spend money at non-essential shops during a lockdown and are forced to save up money as they have way to spend money to fulfil some of their needs. But once a lockdown is lifted they have two things: (1.) highly unfulfilled needs, and (2.) a lot of available money. We see that consumers start throwing money at the non-essential shops to fulfil these needs which gives the non-essential shops a big boost in revenue. Also, when a lockdown is lifted the need for food-safety is, relative to the other needs, low as essential shops, with food, have remained open. Agents choose to prioritise to satisfy their other needs over food-safety, thus spending most of their money. This causes for more people to be seen as "in poverty" due to way we measure poverty: if an agent doesn't have enough money to buy two sets of rations it is seen as being in poverty. So, due to the lockdowns, we first see people getting richer, but once the lockdowns are lifted they (temporarily) become impoverished.

This dynamic also affects the supply chain. As workplaces produce less and essential shops sell more, the stock reserves of the workplaces is going down. In our current simulation the workplaces have enough in stock to be able to supply the essential shops during the lockdowns, but the workplace reserves are more than 50% depleted. So if the lockdown would last twice as long, or the initial stock in reserve would be halved, the essential shops would run out of goods to sell, possibly causing them to go bankrupt and maybe even a famine in the town.

The point of economic reserves is also relevant for the non-essential shops and their workers: while they still have money they can pay the wages during the lockdown, but once they run out of capital the wages stop being paid. We see this reflected in the higher amount of workers being in poverty, despite the average workers capital being higher than the baseline and no-lockdown scenario. Non-essential shops don't go bankrupt as their stock is frozen during the lockdown and they can instantly resume operating once a lockdown is lifted in our current model. People spending a lot of money to satisfy their needs helps the non-essential shops to kick-start them and restore some of their financial reserves to pay wages and buy new stock.

In the last scenario, we primarily see a difference in the workers capital, essential shop profit, the velocity of money and government reserves when we compare it to the lockdown with no subsidy scenario. This difference show that workers have more money available and thus spend more. The other parts of the system behave the same as in the basic lockdown scenario.

9.6.1 Research Questions

Above, we have discussed the results for each scenario in relative isolation but our main goals are of a broader sense. Let's recall our issues to investigate in this chapter:

1. Investigate the effect of a pandemic on our economy.
2. Investigate the effects of measures taken to stop the pandemic on our economy.
3. Test various economic measures that could mitigate the negative effects stemming from the pandemic.

In the rest of this section we will structure the discussion based on these general goals. In order to discuss these goals we first want to get back to some of the basic principles of the ASSOCC model. The economy is driven by the needs of our population. Both performing work and buying things is driven by the needs, not a static rule that people have to work and buy food. Where they spend their money is also driven by the needs system. As discussed in our baseline scenario, we see that this sets the whole consumer economic system in motion as they need money and/or require goods to perform the actions. If peoples' needs change, e.g. during a pandemic, so does the way the economy behaves.

Another aspect of the ASSOCC model that is important for the economy is the supply chain that can have a profound effect on the ability of the economic system to satisfy needs. As discussed while analysing the third scenario in Sect. 9.6, when workplaces have less workers, or workers working from home and being less productive, they produce less goods to sell to shops. If shops keep selling more goods than the workplaces produce they will run out of stock, and after a while the shops will do the same. When this happens people can no longer satisfy their needs by shopping and, among other, their food-safety and luxury are unsatisfied. Thus we see that, although we did not implement the economic aspect by adding a money

need, the possession of money does influence indirectly how needs can be satisfied and the satisfaction of needs influences where money is spend and whether money can be earned.

9.6.2   Investigate the Effect of a Pandemic on Our Economy

We discussed most of the effects of the pandemic in Sect. 9.6 with our overall analysis of the second scenario. Here a pandemic causes people to get sick and possibly die. People who are sick (or dead) will not perform work. This causes a clear shortage of labour for workplaces, shops, hospitals, schools, etc. This can cause a supply chain problem, such as closure of shops or lack of stock to sell.

In our model, shops continue to operate if their employees are sick and at home, which could be compared to hiring temps in the real world. But we do expect that the effects of the large amount of sick people will be more severe than our simulations show due to these complicating factors in the supply chain. We could also expect this to happen with the healthcare system. If no capacity is available, e.g. due to sick doctors, we will expect to have a higher mortality rate and, thus, a bigger effect on the economy.

Another effect that we see is that sick people only shop for the bare necessities and spend less money on other things. We see this represented in the decrease of the velocity of money, as seen in Fig. 9.15, and the decreased profit of non-essential shops. Also the dynamic of people getting richer and spending more once the pandemic if over is reflected in this graph.

After the pandemic, the system recovers in our simulations. But this is also where our uncertainty of the economic effects increases. We assume, for instance, that people who do not work during the pandemic can instantly resume working at their old job. We also assume that shops and working places don't close down indefinitely after running a deficit for a while, they don't really go bankrupt. Although this seems a severe limitation of the model it is also a very simple way to model that some companies might go bankrupt (seize to operate), but new ones will be founded as soon as the opportunity arises. In our model these new companies are simply the old companies that resume operation. For longer term simulations it is an interesting avenue for further expanding the economic model: how to deal with closing establishments, letting them go bankrupt and fire all employees and once the pandemic is over founding new businesses and finding new employees (a job market?) and possibly having some shift in types of economic activities. As we do not consider these macro-economic effects in our models we leave this for future work.

9.6.3 Investigate the Effects of Measures Taken to Stop the Pandemic on Our Economy

The main measure investigated in the scenario is the 10-5 lockdown. As said before, this means that a strong lockdown is enforced once 10% of the population is infected and lasts until the numbers are down to 5% infected. This results in less people getting sick at the same time and spreading the infection of the total population over a longer period of time. The resulting dynamic is a wave pattern that slowly dies out, like the waves resulting from dropping a stone in a still pond.

This leads to a very different economic dynamic as we have abrupt changes instead of gradual effect without the lockdowns. Goods production goes down instantly, non-essential shops close and can no longer sell things, the velocity of money goes down and the government loses money by not receiving taxes. People with pensions or other government financing get richer as they can't spend their money. Shops affected by the lockdown run out of capital and can no longer pay their workers. Essential shops on the other hand make a lot more profit by being the only open shops and having customers with more disposable money. Once the lockdown is lifted we see that people go on a shopping spree due to their depleted needs, which has a small reinvigorating effect on the economy. But this also leads to a massive amount of contacts at the non-essential shops and could undo part of the epidemiological effect of a lockdown by creating a potential super-spreader event. This is illustrated in Fig. 9.26 showing the amount of contacts people have in the lockdown with wages scenario.

An interesting connection between the economic model and the epidemiological model is the duration of a lockdown. In our simulations the first lockdown lasts roughly 5 weeks and the next lockdown starts roughly 3 weeks after the first is lifted. During the beginning of first lockdown non-essentials shops have a reserve to pay wages, despite being closed. Most of them run out of money to pay the wages during the lockdown, which means that the workers of those shops need to use their own financial reserves to buy food at the essential shops. We can clearly see this in the increase of workers that end up in poverty (see Fig. 9.13) and the spike when the lockdown is lifted. Unfortunately the three weeks of no-lockdown isn't enough to replenish the reserves of the people or shops and we see that the effects of the second lockdown on the amount of people in poverty is stronger than the first.

An other metric that we track is the quality of life. During the lockdown period the average quality of life goes down at the start of the lockdown, but seems to stays stable at that level during the rest of the lockdown. This level of quality of life is higher than the quality of life level during a no-lockdown infection. That the quality of life stays stable also shows that the increased number of people in poverty only have a small to no effect on the average quality of life. It seems that the other effects of the lockdown have a bigger impact on the quality of life.

This gives us interesting things to consider when talking about lockdowns and the economy. Longer lockdowns have a bigger effect on the financial position of shops, workplaces and people, which is directly related to their reserves in capital
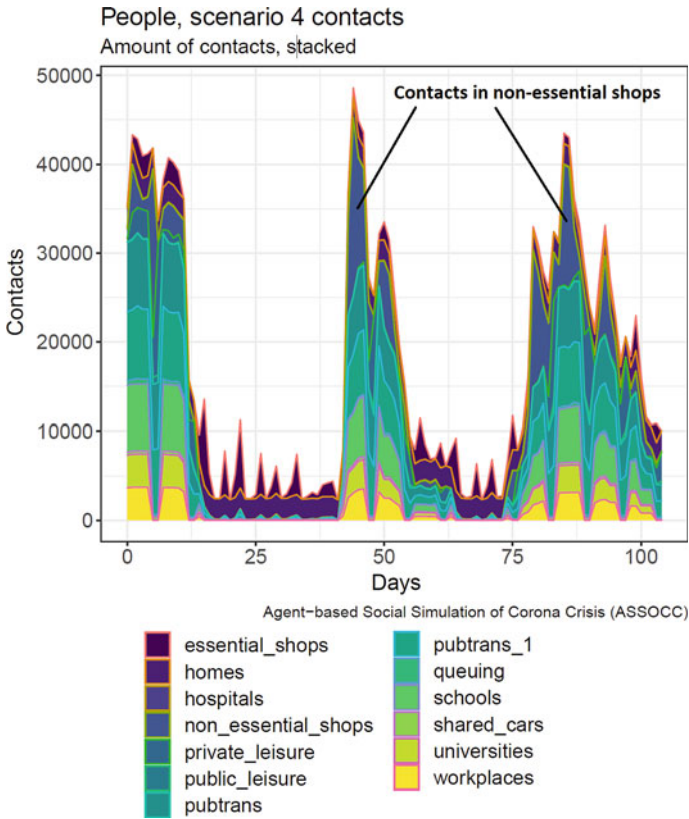
Fig. 9.26 Contacts in scenario 4 showing a big amount of contacts in non-essential shops after a lockdown is lifted

and goods. It also seems that repeated lockdowns have a big effect on the economy when the time between lockdowns is not long enough to fully recover. So on one hand we would prefer longer lockdowns to prevent multiple lockdowns (wave effect) with a lot of potential damage to the economy, but on the other hand one would like to have shorter lockdowns to prevent reserves from running out causing a lot direct harm to the economy.

9.6.4 Test Various Economic Measures that Could Mitigate the Negative Effects Stemming from the Pandemic

We investigated the effect of paying wages by the government of closed shops once the shops run out of capital to pay wages. The effect of this is that workers have more money available, which they in turn spend at the essential shops who seem to be

the main other benefactors from this measure. This is also represented in the higher velocity of money in this scenario compared to the lockdown—no wage subsidy scenario. This does result in more debt by the government despite receiving more taxes from essential shops.

The extra available money also leads to less people in poverty and a bigger shopping spree once the lockdown is lifted. This could lead to an even bigger negation of the epidemiological effect of the lockdown as more people go to shops and cause super spreader events. Which is an interesting finding: paying (more) money to people who can't work will enable them to do more activities once the lockdown is lifted and brings them in contact with more people which in turn can spread the disease more effectively.

Other measures have not been investigated due to time constraints. But one could think about implementing measures to prevent shops from using all their reserves such that they have more leeway once the measures are lifted. We also realise we have effectively implemented a job security measure as workers are not being let go from their jobs. We expect that the quality of life of workers will decline further if they can lose their job and the government does not pay a subsidy or their wages to prevent them from being fired. We also expect that the recovery of the economy will be slower as people need to find new jobs instead of instantly resuming being productive.

9.6.5   General Discussion

Taking in all our results and discussions so far it seems to come down to a trade-off of health and lives versus economic impact. In our simulations, the repeated lockdowns (wave effect) are more harmful to the economy than just letting a virus spread in a natural way. Before we translate this result to the real world, we have to stress that there are many things that we haven't taken into that can influence our findings. For example:

Long term effects on health   During the course of 2020, it became clear that quite some people who have been cured from COVID-19 have long lasting side-effects. These impacts their productivity and might cause additional expenses for a long time to come.

Reinfection   We assume, that reinfections are not possible. But by now we have seen instances where this has happened. If this becomes a bigger issue the idea of "just letting everyone get infected and we're done" won't hold and the economic difference between no-lockdown and lockdown could be very different.

Productivity at home   We assume, that people are 50% productive at home. We know, some people are more productive and some are less, heavily depends on their needs, family situation and type of job. Having empirical data on this would improve the realism of the simulations.

Public sector and the economy   The only part of the public sector included in our economy model is the government as a financial institution. Elements such as public transport, healthcare & schools (other than paying wages) or many other public elements that are critical for the economy are not included for economic analysis.

Long term effect of loss of life on the economy   In our model, people who die only seize to be consumers and are easily replaceable at their workplaces. In reality, they also take a lot of knowledge and know-how with them and are not as easily replaceable. How would this affect the economy?

Vaccines or other cures   We have not implemented a cure for the disease, yet this could be compared to the increased number of immune people in the simulation. But the way one would vaccinate a population could affect the economy. Would you first want to vaccinate certain sectors of the economy? Or certain age groups? Or even certain geographic locations? All these choices will most likely have different economic effects.

9.7 Conclusion

In this chapter, we have shown how one can add another relevant aspect for society of a pandemic to the ASSOCC model. The homeostatic needs model as foundation gives us great tools to explore the problems and creates the main drivers for our agents to partake in an economy, By implementing a "simple" economic model such as the cycle of income, we can create a decent economic system to experiment with in the context of a pandemic.

These experiments have show the relationships between the epidemiological effects of a pandemic and the economy. We have spoken about the wave effect that we see due to lockdowns, which that has by time of writing this chapter also seen in real life by Statistics Netherlands (CBS) [7]:

> In 2020, the Dutch economy showed strong undulations: from severe contraction during Q2 to extreme growth in Q3; however, the latter trend was too weak to compensate for the contraction in the first two quarters.

The Netherlands has been in lockdown during Q2 of 2020 and lifted the lockdown in Q3 of 2020. In the end of Q4, a new lockdown has been set in place and it will be very interesting to see how this "lift" of the economy looks like once that lockdown is lifted.

In our model, we measure the quality of life to gain insight how society is doing. In the economic sense this you could see this see this as an alternative for GDP, one of the key metrics that is used to see "how well we are doing economoically". Despite not having measured the GDP and only the velocity of money we assume the GDP to have plummeted during the lockdowns and during the height of infections in the no-lockdown situation. But we found that these economic aspects only have a minor effect on the quality of life where other things, like not being able to meet

other people, have more effect on the well being of people. The mental effects on well being, for example through needing fulfilment of self-esteem or belonging, is a serious aspect of the economic measures being taken. Of course if people have no money to buy food that will be a problem, but it seems in our analysis that the lack of consumption is not a very big influence on the well being.

In the end, it all comes down to how much value we give to a human life and physical health. Trying to save everyone by having a lockdown until the virus has disappeared is economically very costly. How we should value the infection of someone in an economic way is hard to say as we only have limited knowledge about the consequences. What are the long term effects of a virus? How immune are people after being infected or vaccinated? Without answers to these type of questions it will most likely remain educated guesswork on what the best measures will be if we want to optimize for both the economy and the well being of our population.

But what we can say is that choices have to be made. Choosing for better physical health by reducing contacts, e.g. with lockdowns, will mean more negative effects on the economy. Choosing to not limit economic activity will cost us more lives and will cost us a lot less money in the short run, but holds more uncertainty for the future.

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