Chapter 16
Disaster and Regional Research

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16.1 Disaster Impact Analysis and Regional Science

Natural hazards, such as earthquakes, severe storms, flooding, wildfires, and so on, have threatened societies and economies across the world and have brought considerable damages and losses to our economy, resulting in disasters. Some recent studies indicated that the economic costs of these disasters have been rising (Adam 2013), whereas other studies showed no such trend (Okuyama and Sahin 2009). Whether or not the decisive long-run trend of increasing economic costs of disasters is confirmed can be investigated elsewhere, but what is certain is that as the world economy continues to grow and our wealth continues to rise, at risk assets and populations have also been increasing.

While the impacts of disasters sometimes become catastrophic in terms of economic damages and losses, Albala-Bertrand (2007) claimed that for most countries a severe natural hazard causes localized damages and losses on capital and activities but may not affect negatively the macro-economy in either the short-term or long-term. Except for small island nations and the least developed countries in which even a natural hazard with limited damages to their capital can still lead to the catastrophic disaster causing macroeconomic impacts, empirical analyses of disaster impacts on the national economy appear to support Albala-Bertrand's assertion. Cavallo et al. (2013) found that even very large disasters do not cause any major effect on long-run economic growth, and Felbermayr and Gröschl (2014) concluded that only temporary production losses in the year the disaster occurred are statistically significant without finding any subsequent long lasting effect on production level.

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At a regional level, on the other hand, the economic impacts on a disaster-struck region can become quite substantial in terms of their intensity and extent. In such cases, economic impacts result not only from the damages and losses caused by a natural hazard per se, but also from recovery and reconstruction activities after the event. These damages and losses, and the recovery and reconstruction activities are all regionalized (localized) incidents leading to quite extensive impacts and effect on the region. The sub-national (regional) analysis of disaster impacts is an important avenue for the future direction beyond national level research (Mochizuki et al. 2014), which has been conducted more often than regional empirical research on the impacts of disasters. For example, DuPont and Noy (2015) and Okuyama (2016) examined the long-run effect of the 1995 Kobe earthquake on the regional economies and found sizeable and intricate effects of short-run impacts and long-run effects from negative shocks as well as from positive demand injections of reconstruction activities. Regional analyses of disaster impacts can utilize a wide array of regional science methods and the current and future regional research agenda should include disaster impact analysis.

Meanwhile, the complexity of global production processes has made impact propagation to other regions within the country and across national borders more likely. Interregional analysis of disaster impacts has been conducted, such as the evaluation of interregional impact within a nation (Okuyama et al. 2004 and Tsuchiya et al. 2007) and across countries (Arto et al. 2015). Whereas the propagated impacts to other regions are smaller than the impacts in the region struck by a disaster, these studies find some evidence that impacts diffused interregionally, causing negative or positive impacts in other regions. Therefore, in addition to the need for regional analysis of disaster impacts discussed above, interregional analyses have also become more important in comprehensive disaster impact analyses.

In this chapter, what the regional research in disaster impact analysis will and should become in the next 50 years are presented and discussed. The following section time-travels to 50 years into the future, witnessing the launch of an integrated simulation system for disaster impact analysis, the World Disaster Impact Simulation System (WDISS). The third section describes the technical features of WDISS. The historical development of WDISS is illustrated in the last section.

16.2 Introducing the World Disaster Impact Simulation System

On January 17, 2065, an international organization, the World Disaster Consortium, introduces the World Disaster Impact Simulation System (WDISS), which enables local, regional, national government, or international organizations and their decision makers to simulate disaster process and impact with a given natural hazard for examining mitigation and recovery strategies as well as for planning preparedness and response against such events. This system utilizes a standardized platform for disaster impact analysis, constructed on a significantly extended version of the HAZUS system developed by the Federal Emergency Management Agency (FEMA) of the United States several decades ago.[1] Because earthquakes, hurricanes, typhoons, wild fires, flooding, and so on have become more intense and more frequent, due partly to global climate change and planetary geological activities, it is imperative to address how societies can deal with disaster situations. While WDISS is the state-of-the-art system for disaster impact analysis, it does not include a prediction or forecast module of natural hazard occurrences, since even now such prediction or forecast has not sufficiently progressed.[2] WDISS utilizes data generated from agencies such as geological or meteorological agencies, for hazard occurrence, intensity, projected routes, etc.

While controlling sternly and tightly the privacy and security of information used, WDISS is intended for public sector use, from the local to the international level, in order to be applicable to any natural hazard and disaster situations.[3] WDISS has an interactive interface with a superb visualization capability and includes several modules to simulate the highly complex processes of a disaster's aftermath and reconstruction on a broad range of social, economic, demographic, behavioral, and environmental dimensions. The overall structure of WDISS consists of three layers: (1) immediate damage and loss assessment; (2) comprehensive impacts estimation; and (3) analysis of recovery and reconstruction strategies and their effects.

To achieve such noble goals, WDISS has the following three major features: seamlessness; comprehensiveness; and, adaptability.

16.2.1 Seamlessness

WDISS can analyze disaster impacts seamlessly over space and time. Damages from a natural hazard are mostly localized but sometimes they reach multiple countries, for example the damages from the 2004 Indian Ocean Earthquake and Tsunami. Because higher-order effects, i.e., ripple effects, from the disaster damages can propagate across the globe via supply chains, for instance the impacts on automobile industries across the countries by the 2011 East Japan Earthquake and Tsunami, the geographical extent of simulation should not be limited to the nation hit by a natural

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[1] https://www.fema.gov/hazus (accessed on January 13, 2016). The first version was released in 1997.

[2] On the other hand, the global network of multi-hazard early warning systems was greatly improved under the Sendai Framework for Disaster Risk Reduction 2015–2030 (UNISDR 2015) and had been completed during the Tokyo Framework for Disaster Risk Reduction 2030–2045, which was adopted after the 2027 Great Tokyo Earthquake.

[3] WDISS deals only with natural events, but not man-made events, such as terrorist attacks or war, because we wish that such man-made events did not exist by then.

hazard. Hence, WDISS accommodates a wide variety of spatial extents, from a local area to the entire world, depending on the distribution of damages and losses in a particular disaster situation. Additionally, a disaster simulation system should be able to model a range of activities over time, from emergency response immediately after the event occurrence to evaluation of the effects from reconstruction in the long run (Rose and Guha 2004). These phases consist of quite different activities in terms of their nature and consequences, yet their impacts overlay each other to create complex effects.

WDISS permits users to explore seamlessly impact propagations over space and time, so that decision makers and governments can decide how and to what extent they need to respond and can consider mitigating further effects. This is a major advancement over previous approaches.

16.2.2 Comprehensiveness

In earlier generations, research in disaster impact analysis was mostly limited to specific impacts, such as economic, social, environmental, or others. In WDISS, most aspects that are considered as disaster impacts are included and integrated, such as industries, institutions, capitals (physical, human, social, etc.), environment, and so forth, in order to simulate the impact propagation of a disaster comprehensively. Therefore, several aspects often omitted from impact modeling in the past can be taken into account, including financial, domestic and international aid, and environment. Financial aspects of disaster impacts, including distributional effects, have been discussed for some time (Rose 2004), but have not been integrated well into disaster impact analyses. While the financial condition of most advanced countries may not be significantly affected by even a severe natural hazard (for example, the 2005 Hurricane Katrina in the United States and the 2011 East Japan Earthquake and Tsunami), it becomes quite different for many developing countries, especially for small island nations.

In the meantime, some catastrophic natural hazards also damage the natural environment (for instance, the damaged coastal areas after the 2004 Indian Ocean Earthquake and Tsunami) and/or a drastic reconstruction strategy may alter the surrounding natural environment (for example, the extensive resettlement to higher elevation after the 2011 East Japan Earthquake and Tsunami), which would cause long term effects for the respective and surrounding ecosystems. While in the past it was considered to be inexhaustible, the environment is now considered as a limited property (capital) (Krugman 1998). Therefore, it is included in WDISS as a part of capital that can be altered during the aftermath of a disaster to evaluate the interactive and comprehensive impacts and effects from the respective event.

16.2.3 Adaptability

One of the unique and advanced attributes in WDISS is its adaptability, which comprises flexibility and resilience. Flexibility implies the flexible settings of policy variables and regional attributes. The respective local or regional government hit by a natural hazard can highlight some specific local characteristics and policy implications, such as impacts on natural resources and/or changes in inequality of income distribution, to obtain more locally oriented results. Whereas WDISS has the standardized framework for disaster impact analysis, it can emphasize a range of local attributes and change the priorities for policy variables and options. Allowing this type of analytical modification enables policymakers to define a set of alternatives and choices, while WDISS still derives a result using the standardized setting as the benchmark. Although the main features of WDISS intend toward the macro-perspective covering the affected region as a whole, there are some optional modules for micro-perspectives, such as for first responders, for evacuation strategies either in short- and long-runs, for distribution of relief goods, or for information provision to affected company's business continuity plan (BCP) operation. These modules are available in a standardized form and can be localized during ex-ante user training phases.

Resilience of a society has been a topic of discussion for the past 50 years and modeled in disaster impact analyses to some degree, for example, in the context of industrial production (Rose and Liao 2005). In addition, a broader notion of resilience was proposed as post-disaster endogenous response, in which many factors of a society cope endogenously under a disaster situation (Albala-Bertrand 2013). In WDISS, this resilience is defined as adaptability that is formalized and endogenized with exogenous policy variables, which can change the degree of adaptability under a disaster situation of a particular process. In this way, the policies to enhance adaptability of business operation in a disaster situation, for instance business continuity plan (BCP), can be evaluated for the ex-ante analysis. Furthermore, unintended but related impacts (final demand losses) caused by unfounded rumors and voluntary restraint, whose degree can be dependent more on the cultural background of a particular society, can be also evaluated as changes in social adaptability. WDISS has variables and flexible settings to model such adverse behavioral changes on the respective economy, even though they may be short-lived.

In addition to these three major features, WDISS has several methodological elements that enhance simulation capabilities and the robustness of the results. Such elements include real-time monitoring and simulation capability, stochastic simulation with a variable range of uncertainty, and disaster database and knowledge-base construction. Since these elements are more technical in nature, they are discussed below in the technical notes.

16.3 WDISS Technical Notes

WDISS overcomes several technical challenges and has achieved breakthroughs for its realization and operation. The overviews of such technical breakthroughs are briefly described below.

16.3.1 Analytical Framework and Theoretical Underpinnings

Since the data points have been limited due to the infrequent occurrence of disasters (of course, this is a good thing for society) and each natural hazard is a unique event, it is difficult to generalize how disaster impacts would develop and impact the affected region. In the past, research on regional economic impacts of disasters has been mostly empirical and case specific. This tendency influenced the framework and even the objectives of analysis, which can differ from one study to another, leading to conflicting conclusions even when the studies dealt with the same event (Hallegatte and Przyluski 2010). As such, setting the standardized framework of disaster impact in terms of the aspects, duration, and geographical space to be covered was essential to the construction of a common simulation platform for a wide variety of disaster cases. For example, in terms of duration, earthquakes happen within a few minutes but reconstruction can take several years, while flooding may last up to a few months and might require only a few more months to rehabilitate the damaged regions. Therefore, the flexibility of the definitions was a key to an effective simulation system. Seamlessness, one of the major features of WDISS, allows for suppleness of attributes so that the users can choose or explore the simulated extent and duration of a disaster.

While suppleness is necessary, robustness of simulation results across various settings is important to generate reliable policy recommendations. To make the system robust across a wide range of settings, the theoretical underpinnings of disaster processes should be placed firmly, for example how people and institutions react and respond to a disaster situation. Since the pioneering work of Dacy and Kunreuther (1969), theoretical investigations of disaster impacts and reconstruction processes had been limited for both short- and long-run effects (Okuyama 2007). Through empirical research based on comparison across disaster cases using the standardized definitions, whose findings have been accumulated in the World Disaster Database, theoretical investigations of behavioral changes under a range of disaster situations have been conducted and have developed and tested disaster theories since the late 2010s. In WDISS, some policy variables, for instance the schedule for recovery and reconstruction activities, can be controlled exogenously by users (or can be endogenous for deriving an optimal case), several behavioral variables, such as the responses and reactions of private companies and households, are endogenous to the simulation model so that the results can reflect behavioral changes and reproduce adaptive behaviors. The model also can deal with the possibility of multiple equilibria or complex system outcomes, hinted from Davis and Weinstein (2004) when they modeled the reconstruction of the Japanese industries from World War II.

16.3.2 Modeling Scheme

Because a disaster process is a multi-aspect event that impacts physical, economic, social, demographic, financial, and environmental systems, a comprehensive event simulation calls for a multi-dimensional system capable of integrating the various aspects of the impacts. Within each aspect, some factors interact while others are interdependent from each other, resulting in a multi-layer modeling structure. Combining all of these results in a large system, while persistent advancements in computational capability and data availability to this date have eliminated computer hardware or software as a binding constraint on the implementation of WDISS. Rather, the remaining issue was the modeling scheme and data structure of such a complex system. For each aspect, separate models have been available and have been employed in disaster impact analysis independently. The effective integration among these various aspects is the main and most crucial part of WDISS. In the past, multidisciplinary studies proposed a series of integrated models, such as socio-economic models, demo-economic models, and transportation (physical)-economic models (see some examples in Okuyama and Chang 2004). Comprehensive analysis of disaster impacts in WDISS required further integration of these aspects in an effective and proficient way.

To integrate multiple aspects, the data structure and the linkages among aspects have to be managed to make them consistent across the board. For instance, some physical and economic aspects use quantitative values, while social and environmental aspects often employ qualitative information. Even within quantitative data, a physical aspect is usually measured with the metric system, whereas an economic aspect is most commonly expressed in monetary scale. On top of this, to facilitate seamless integration across the aspects, micro-level data and macro-level data need to be consistent. This was actually quite difficult to do in the past. For example, information about local economies, even in advanced countries, did not add up to their equivalent data at the national level due to statistical discrepancies and measurement errors. Seamlessness over time was also problematic because of data availability, since most of the official data represented a point in time or the aggregate over a given period of time, rather than being provided in continuous form. The seamlessness of simulation does not require data in a continuous form, but the suppleness to use shorter periods, such as a week, and the consistency among various time frames had to be achieved. These issues have been addressed and mostly overcome with recent advancements in the accuracy and frequency of data collection, led by the United Nations Statistical Office (UNSO). The data used in WDISS follows mostly the UNSO systems in addition to exclusively collected data as well as on-going disaster data, such as damage and casualty data that can be collected in real-time using the dedicated satellites and monitoring systems of WDISS.

16.3.3 Methodological Elements

WDISS incorporates advanced methodological elements. One of them is the real-time monitoring and real-time simulation capability. Whether a natural hazard is occurring over a relatively short period (for example, earthquakes) or over a long period (as in some cases of flooding), timeliness of gathering and collecting damage data is essential for the relevance of simulation result. In addition, because recovery and reconstruction activities are often faster paced and more regionally concentrated than similar operations in ordinary circumstances, such as large construction projects, monitoring them in a careful and continuous manner is necessary to evaluate the progress and further effects emitting from them within the region and across other regions. Whereas such technologies for real-time monitoring systems are in an engineering domain, real-time simulation capability can be discussed in the context of various modeling frameworks, including economic, demographic, and environmental.

Another methodological element in WDISS is the capability of stochastic simulation. Stochastic processes have long been central to robust analysis of simulation forecasts or projections. Moreover, a disaster often increases uncertainty of perceptions toward the future, leading to variations in behavioral changes by the affected people and institutions. Stochastic processes are able to accommodate such fluctuations in uncertainty, while theoretical corroboration for how the alterations of behavior occur in a disaster situation determines the range of variations.

WDISS is not only a simulation system but also comprises the disaster data and knowledge base. It accumulates the simulation results as well as the actual outcomes based on the decisions made during use. These data are then stored in the system’s data and knowledge base that is linked with the World Disaster Database, which includes outcomes of past disaster research, from short-run impact assessments to long-run effects analyses. The system’s data and knowledge base is employed to improve the expert system through deep-learning of actual disaster processes. This also enables archiving of the disaster data and policy outcomes for ex-post analysis of a particular disaster process to examine how and to what extent the recovery and reconstruction plans alleviated the potential effects. This type of research is critical to mitigate and prepare for the future disasters.

16.4 Brief History of WDISS Development: Regional Scientists at the Helm

WDISS is a highly complex modeling system integrating various aspects from economy to environment. Its development required a broad range of expertise, from physical sciences and technology to social sciences. Therefore, WDISS became a multi-disciplinary project with the participation of numerous researchers and practitioners from different fields. In the early stage of its development, after starting the project in 2017, disaster scientists led the project. However, due to the complexity of disaster impacts and the difficulties of dealing with tradeoffs among various problem domains, the development process became disorganized. A team of regional scientists finally took over the leading role in the project around 2025, because of regional scientists' skills in integrating a diversity of empirical models. Furthermore, in terms of the seamlessness of WDISS over space and time, regional scientists had experience relevant to the analysis of disaster impacts over space (Tsuchiya et al. 2007) and time (Donaghy et al. 2007), and thus were able to extend the model to the time-space continuum in an empirical context, a challenge that had been monopolized by physicists since Einstein. Recent generations of regional scientists have broadened WDISS features to deepening our understanding of disaster processes, adding, for example, spatial analyses of disaster impacts and reconstruction effects to examine spatial externalities. Regional scientists have been particularly well suited to the leading role, continuing in the traditions of the father of regional science, Walter Isard, who declared that: "the field of Regional Science has been and is interdisciplinary" (Isard 1998).

After regional scientists took over the helm, the development process progressed very smoothly. However, the Great Tokyo Earthquake occurred in 2027, which changed our perspectives of disaster impact considerably. Not only were the numbers of casualties and damages on every aspect of the society beyond the ex-ante estimations, but so also were the impact propagations over space, time, and extent unprecedented. Every catastrophic disaster had significantly changed and expanded our understanding of disaster impacts, such as the 1995 Kobe Earthquake, the 2004 Indian Ocean Earthquake and Tsunami, the 2005 Hurricane Katrina, the 2010 Haiti Earthquake, and the 2011 East Japan Earthquake and Tsunami to name a few, and this 2027 event was not an exception.

The project team had to reconsider extensively the system structure to incorporate the lessons learnt from the 2027 event and its consequences, and finally revised its overall structure and the standardized definitions of disaster in 2032. Based on this common framework, the past disaster cases were retrospectively re-evaluated and the results were fed into the World Disaster Database for contributing to the development of new disaster theories. Scholars from a broad range of fields participated the theoretical development of the system, from disaster scientists and geophysicists to ecologists and sociologists, and even economists. The developed disaster theories in each field were harmonized for the integrated framework utilizing the technique inspired by Lisi (2007). A primary version of the unified theory of disaster was formulated in the mid 2040's, and the project team initiated programming of the simulation system based on it. The unified theory has been continuously updated employing the World Disaster Database and the system's data and knowledge base, fine-tuning the structure and parameters of the simulation system.

During the 2050's, a series of satellites and ground level equipment for the monitoring network that collect data and monitor disaster processes for the simulation system were launched and placed. At the same time, a sequence of calibrations and perfections of the system was carried out in this period using some disaster cases in this period. The final step of the system construction was to incorporate with the artificial intelligence sub-system with nano-programming (Parisi 2012) that is able to self-debug the programs and to self-update and even self-regenerate the system within the pre-determined framework. In this way, the completed WDISS system no longer has a version number, which was a common practice for software in previous generations. After the final adjustment processes and some test runs, WDISS was released in 2065.

Whereas the occurrences of natural hazards cannot be prevented, their impacts can be mitigated and reduced with appropriate countermeasures based on disaster impact analyses. The release and utilization of WDISS is expected to contribute now to the safety and security of all humankind.

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