MAJOR DISASTERS IN MODERN ECONOMIES:

AN INPUT-OUTPUT BASED APPROACH AT MODELLING IMBALANCES AND DISPROPORTIONS

Marija Bočkarjova

2007

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DISSERTATION

to obtain
the doctor's degree at the University of Twente,
on the authority of the rector magnificus,
prof.dr. W.H.M. Zijm,
on account of the decision of the Doctorate Board,
to be publicly defended
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by

Marija Bočkarjova
born on 26 August 1978
in Riga, Latvia

This dissertation has been approved by:

Prof. dr. A.E. Steenge (promotor)

Acknowledgements

"Katrina was big, but God is bigger"
New Orleans, 2005

This project was not a 'standard case', as much as rarely, for as far as my experience shows, either of PhD trajectories is. It started from an initiative of Prof. Steenge to invite a couple of Latvian researchers to participate in one of the running projects at the University of Twente. This way, I came to Enschede to complete my Master studies with a thesis back in 2002 on modelling major flood consequences in the Netherlands. Because the cooperation proved successful, Prof. Steenge offered me to continue the work on this project as a PhD student. At that time, the threat of major disasters was not that apparent, only 1996 European floods were coming to minds of people reacting on the choice of topic, mostly surprised. The Dutch were (and often still are) having a typical answer: "Why? Our dikes are perfectly safe!"

'Fortunately', the awareness of large-scale natural hazards was boosted by the recent events of Asian tsunami and the hurricane Katrina, both of which were of amazing, unprecedented scale and power. Now, when I am completing this thesis, also the general understanding of the use of research such as the current one has substantially increased. In fact, this raises a somewhat peculiar feeling. On the one hand, disasters make a staggering, wild impression, which is provoked by immense damages and human losses, personal dramas and sufferings by those affected. On the other hand, these also make people think about the need for getting to know more about the nature and destructive potential of major hazards to modern societies.

I am grateful to Prof. Steenge and Prof. Van der Veen that this research has become what can be called a 'fundamental inquiry', attempting to shed light on the processes behind a disaster in an economy, asking a number of basic questions. I am also glad to have been involved in the discussions in the context of the Delft Cluster project, where researchers from various backgrounds came together (among others, Ton Vrouwenvelder, Paul Waarts, Eline van der Hoek, Lodewijk Stuyt, Bas Jonkman), and where the differences in approaches between the 'beta' and 'gamma' sciences became so apparent. Yet, I believe, working together to achieve the same goal, we have learnt from each other!

Here, I will mention only a few out of a great many of thank-you's that I would like to say to those people who made the completion of this thesis possible. First of all, to my supervisor, Prof. Bert Steenge, and his wife, Marietta de Waard. I highly appreciate that Bert and Marietta have also become my mentors and friends, which has always given me a comfortable feeling, and in particular in the beginning of the trajectory when I was settling in the Netherlands. Our formal discussions, when Bert was challenging me on many accounts, have greatly stimulated my successful progression; our informal conversations, full of digressions in history and art, have created a fruitful working environment. Now, when the thesis is finished, I realise very clearly how important Bert's role has been as a supervisor. From the very start, Bert provided me with ample opportunity for visiting and presenting at international conferences, introducing me to the scientific community, which opened many roads. Now, I have to confess that at the end of this research, I have found that Bert's comments, actually, were making much more sense than I thought before; that's when I have discovered with gratitude that Bert has let me grow and develop as a researcher and a personality at my own pace. Also, drafting this thesis, I have received a lot of freedom of giving the research its final form in a single storyline. It took me quite some deliberation to decide where I should start from and what my story will ultimately end up with. Together with the model we developed, these were two crucial issues shaping this book.

Further, it was my pleasure to work together with Prof. Anne van der Veen. I consider it a privilege to have got support, comments and advice from both Bert and Anne (each, in his own way) that have always been a source of inspiration to me, teasing my scientific curiosity.

Ria Luschen, the secretary of our department, deserves my special thank you for her unbelievable ability to sense your needs and find the best way of solving your problems. Ria, you have made my life so much easier! I am in particular grateful to you for the meticulous work with graphs and formulas, your patience in bringing changes every time we came up with alterations. You have saved so much of my time when I needed it for working on the last reviews of the draft.

I should also mention the enjoyable atmosphere at the University of Twente that was, among others, created by my peer PhD students. It has always been '*gezellig*' (the scope of this exclusive Dutch word can be translated into English, depending on the context, by at least five to ten synonyms, like pleasant, comfortable, cosy, entertaining, sociable, convivial, etc…) to watch a movie, have a pizza or play a round of bowling, discussing 'typical PhD matters'. Among others, I should mention Michel, Alina, Wilbert, Martin, Boriana, Sebastiaan, Henk, Peter, Caroline, David, Mark, Arno, Tieneke and Katharine.

I am highly indebted to Prof. Piet Rietveld and Prof. Erik Verhoef for giving me an opportunity to start working as a postdoc researcher at the Department of Spatial Economics at Vrije Universiteit Amsterdam, while finishing my thesis at the University of Twente. Their flexibility, understanding and support proved crucial at this final stage of my research. I am grateful to Erik Verhoef for his sharp feedback on the early drafts of my modelling chapters; to Jeroen van den Bergh for his attentive lending of the books that proved very helpful; to Henri de Groot, Jos van Ommeren and other colleagues from the Spatial Economics department for their positive attitude and enthusiasm; and to Marjan Hofkes, Roy Brouwer, Laurens Bouwer and Wouter Botzen from IVM for their interest in my research. I am glad that at VU I have found a place that is as inspiring as demanding for continuing my journey of scientific discovery.

A number of people from the scientific community have also contributed to the success of this thesis through the valuable feedback on our presentations, as well as informal discussions at the international symposia, among others Adam Rose, Henk Folmer, Peter Boorsma, Arjen Hoekstra, Sam Cole, Yasuhide Okuyama, Faye Duchin, Reinhard Mechler, Jan Oosterhaven, Erik Dietzenbacher, Robert Denhardt, Bob Cairns, Sandra van Tiel, Mark Thissen, Taka Ueda, Atsushi Koike and Ismena Revina. Also, I highly appreciate those useful pieces of advice that I (unexpectedly, by so much in time) have got from Jürgen Enders, Hans Vossensteyn and Trond Bjorndal; and those valuable references to the literature (some of which, forgotten, I found on my bookshelf!) that I have got from Gert-Jan Hospers. Furthermore, I am very grateful to what is now the School of Management and Governance and the Institute for Governance Studies, IGS (University of Twente), and the Netherlands Institute of Government, NIG, for various grants and overall support of my research.

I am equally indebted to my former tutors from the University of Latvia, Tatyana Muravska, Mihails Hazans, Morten Hansen, Alfs Vanags and Vita King (and many others from the former EuroFaculty staff and the University of Latvia) for their contribution and support that has formed the solid basis for my post-graduate research. Without learning those essential analytical, as well as communication skills during my Bachelor and Master studies in Riga, it would have hardly been possible for me to perform up to the required level during my PhD trajectory.

A number of other people deserve a separate thank you. These are my friends and family. I am glad to have met Svetlana, Tanya and Liudvika, and to have found both colleagues and friends in their face. Discussing matters related to work or just having fun together was always a pleasure. I would also like to thank Alina and Martin for being my paranimphs, and for agreeing to support me during the defence of this thesis.

It would be much more difficult to go through all the stages of research and drafting this thesis without the valuable support of my husband, his parents, and the rest of his family, with whom I could share my achievements and failures, joys and irritations (whether justified or not), in exchange for which I was getting love, support and an indispensable flavour of Dutch ‘common sense’. Reynoud, special thanks to you for your friendship, love, patience, care and understanding, which I needed so much.

Finally, and most importantly, I would like to say a word of gratitude and appreciation to my Mother for her endless support and unconditional love. It has always been important for me to realise that you are there for me at all times with a certain piece of advice, which testified for your patience and devotion. I highly value your numerous encouragements to continue my studies, which every time gave me a new impetus to stay strong and to go on achieving a next goal.

Спасибо!
Paldies!
Dank u wel!
Thank you!

Marija Bočkarjova
Deventer, June 2007

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“Risk society is a *catastrophic* society.”

Ulrich Beck, 1992

Chapter 1

Introduction

1.1. INTRODUCTION

It seems that disasters and large-scale ones in particular, are becoming an inevitable part of modern societies. Such calamities as typhoons, vast earthquakes and strong tsunamis are taking place all over the world, endangering the lives of people and their possessions. Indeed, a disaster can be considered a disaster if a natural or manmade hazard is coming in touch with, and is devastating human, cultural and economic assets. As an example of a large-scale event shaking the world we may mention the recent earthquake and tsunami of 26 December 2004 in Asia, the hurricanes Katrina and Rita in the United States (Autumn 2005) and the vast earthquake in Pakistan (October 2005). But let us take a look at the following:

- The Chernobyl accident occurred on April 26, 1986 in Ukraine (then part of the Soviet Union), when the unit 4 reactor of the Chernobyl power plant suffered a catastrophic steam explosion that resulted in a fire, a series of additional explosions, and a nuclear meltdown. It is regarded as the worst accident in the history of nuclear power. Because there was no containment building, a plume of radioactive fallout drifted over parts of the western Soviet Union, Eastern Europe, Scandinavia, the United Kingdom, and the Eastern United States. Large areas of Ukraine, Belorussia, and Russia were badly contaminated, resulting in the evacuation and resettlement of roughly 200.000 people.
- The September 11th 2001 attacks are among the most significant events to have occurred so far in the 21st century in terms of the profound political, psychological, and economic effects that followed in the United States and many other parts of the world. Then, a series of coordinated attacks upon the United States was performed, in which a total of nineteen hijackers simultaneously took control of four U.S. domestic commercial airliners, crashing airplanes into the World Trade Centre in Manhattan, New York City — both of which collapsed, and the U.S. Department of Defence headquarters, the Pentagon, in Arlington County, Virginia. The official count records 2.986 deaths in the attacks.
- In August of 2002 a 100-year flood caused by over a week of continuous heavy rains ravaged Europe, killing dozens, dispossessing thousands, and causing

damages of billions of euros in the Czech Republic, Austria, Germany, Slovakia, Poland, Hungary, Romania and Croatia.[1]

- The 2004 Indian Ocean Earthquake, which seismic moment magnitude was valued at least 9,0 on the scale of Richter, killed following various sources up to 285.000 people (Lay, *et al.*, 2005), making it one of the deadliest disasters in modern history.
- The Kashmir earthquake 2005 was a major seismological disturbance, registered 7,6 on the moment magnitude scale of Richter. The Pakistani government's official death toll was 87.350. Some, however, estimate that the death toll could reach over 100.000.
- The official death toll of hurricane Katrina (2005) is estimated at 1.325 and over a million people displaced. Devastating the city of New Orleans, the damage is estimated to be from $70 to $130 billion, making Katrina the most expensive natural disaster in U.S. history. Hurricane Rita was the seventeenth named tropical storm, ninth hurricane, fifth major hurricane, and second Category 5 hurricane of the 2005 Atlantic hurricane season.

The *size* of the event is the distinguishing feature that unites all these adversities, characterised by vast devastation to physical property as well as often stunningly high human losses. The unprecedented rage of these events makes them appear on the top of the agenda of both public and academic debate. A number of questions arise in this respect, however. Some of the most obvious are: Are these devastating events to happen again in the future? How vulnerable are we to such events if they hit us again? Can we prevent such calamities from happening in the future? And: can we prepare ourselves to these events?

These questions, although they may seem simple, raise fundamental issues of attitude towards disasters in contemporary societies. We may notice that risk, and especially very low risk (of a very big event) is treated differently by individuals than, say, prospects for benefits or the chance of good luck. This phenomenon was first observed by Kahneman and Tversky as a duality of decision making (see Kahneman and Tversky, 1979). The so-called ‘certainty effect’ (described as giving less weight to outcomes that are merely probable in comparison to outcomes that are realized with certainty), following the authors, contributes to risk aversion in situations involving certain gains, and to risk seeking in situations involving certain losses. According to prospect theory, people tend to underestimate the risk of losses (in our case, an unlikely but still possible disaster). Even more (*ibid*, p.286) “small probabilities of disaster are sometimes entirely ignored.” The consequence of this is that individuals (who, after all, are society’s constituents) do not properly prepare for an adversity, and are completely taken by surprise when it strikes; a phenomenon that was directly observed in the recent case of hurricane Katrina (2005) devastating the city of New Orleans. This drama has taught us that the awareness of disasters as small chance-high consequence events should be raised in order to help avoid future failures. Actions to be taken should in the first instance include gaining insight into the processes behind a disaster in an established complex system, followed by *a priori* scanning of potential directions in which the economy may develop after a shock. However, it is not possible to think

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[1] A 100-year flood means that a flood of this intensity may be expected to occur, on average, once every 100 years.

about steering socio-economic adjustments and recovery without intimate knowledge of the nature of a disaster. This particular issue has become the pivotal point for the commencement of our inquiry. We shall start with that.

1.2. DISASTERS AS A 'THEME'

A study of the impact of natural disasters as a multidisciplinary effort requires knowledge of the laws of nature, the engineering properties of physical structures, the working of economic systems, the sociology and psychology of individuals, the institutional settings and the political processes behind the planning and implementation of precautionary measures, recovery, and reconstruction – in short, a multitude of disciplines and sub-disciplines. In this thesis, we shall concentrate on only one such dimension, namely the economic side of the 'narrative' behind a disaster. However, we should be aware that influences from all these other fields make themselves felt in the economic sphere. Occasionally we shall encounter them.

We shall proceed this Chapter with the justification and the problem statement for our research, followed by the description of the general research design formulating the scope, aim, research questions and our 'philosophy' behind disaster modelling. We shall conclude with a general outline of the thesis.

1.2.1. Why the Need for Such a Study?

The current study covers the modelling of *major* disasters, i.e. events of a scale that have rarely taken place before. One of the questions that may come up with respect to the chosen domain of research is: why care about such peculiar, uncommon, almost abnormal events if these are unlikely to happen? Or: why should we bother about the methodology for loss estimation if most probably we shall never experience a disaster in real? This is a fair question, to which US National Research Council (1999, p.39) provides a clear answer:

> "…*ex post* measurement by itself does not directly address the […] primary purposes […] for quantifying indirect effects. Determining appropriate amounts of resources for *victims* of disasters cannot wait until after a disaster […] Valuing mitigation requires estimation of expected loss savings over time. Measurement of actual losses from one particular event contributes only limited information for that purpose. Finally, planning emergency response necessarily must precede a disaster."

Provided this, we may justify our choice of subject on the grounds that exploration of major disaster consequences is a vitally important task for contemporary societies in view of their sustainable development[2] objectives (see Brundtland Report (UN, 1987), as well as UN International Strategy for Disaster Reduction, UN\ISDR 2001). However

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[2] Here we interpret the term 'sustainability' in the way it is generally understood today, i.e. as meeting the needs of the present without compromising the ability of future generations to meet their own needs, here following the UN Brundtland Report (1987), p.54. Sustainability is a helpful concept to be employed in thinking about major disasters, especially if linked to the concepts of mitigation, adaptation and resilience, which will be discusses later in this thesis.

unusual a catastrophe may seem to be, its arrival cannot be completely excluded and we cannot afford ignoring that. In this context, we also should refer to the precautionary principle (see World Commission on the Ethics of Scientific Knowledge and Technology, COMEST, 2005). According to this principle, an activity should not be undertaken if one may expect that it will bring substantial or irreversible negative effects. In the case of disasters, one can also interpret it in a slightly different manner, i.e. in terms of activities or policies that have to be implemented, because idleness (‘doing nothing’) may lead to an incident, the consequences of which cannot be precisely estimated in advance, but may be expected to have serious negative or even irreversible effects on the entire economy or society. At the moment that it does happen, it will be too late to think of how it could have been prevented or how we could have prepared for it. In order not to play blind, we have to be aware of the scenarios with the worst expected outcomes. Indeed, therefore we need an in-depth study about the expected effects and consequences of major calamities.

Another question to ask is whether we do need a different kind of analysis of *large-scale* disturbances; that is, when compared with the number of studies on perturbations of a more conventional (‘marginal’) scale. For this, we shall again consult the US National Research Council (1999, p.40):

> “The abruptness, impermanence, and often unprecedented intensity of a natural disaster does not fit the (usual) event pattern upon which most regional economic models are based”.

We may take this to suggest that we need new ways of thinking about disastrous events on a grand-scale. The nature of a disaster presumes substantial harm being brought to a socio-economic system, thereby propagating an uncommon disturbance throughout the entire system. This feature of an aggravating force is shared by almost all major calamities. In fact, as we shall show, it forces us to adopt a different kind of models in order to analyse the essence of these occurrences.

Finally, one may wonder, however, whether the field of disaster analysis exists at all. The point here is that because economic ‘catastrophe theory’ is a compound of studies carried out by scholars of many backgrounds, the existence of a field itself can be questioned. To this end, Alexander (1997, p.297) claims that so far one may observe that:

> “Disaster studies involve a distinctive amalgam of academic and practical considerations, theoretical and applied concepts, social and physical sciences, natural and technological phenomena, and structural and non-structural mitigation methods. The field has benefited from the tension of opposites created by these dualities, but development has been held back by the contradictions that they imply.”

This observation about the fragmentation within disaster studies into sub-fields and specialisation has a number of implications according to Alexander (*ibid*, p.298). Among others, he mentions first that due to a lack of adequate cross-disciplinary training, what he calls ‘the wheel of disasterology’ is constantly being reinvented by specialised practitioners and academics who are unaware of previous work outside their own field. Next, there are few agreed standards and there is no consensus on the body of general knowledge on disasters. Finally, failure to appreciate developments in the fields other than one’s own means that attitudes are not steadily re-calibrated and innovations in theory are not easily propagated.

Views like the above have strengthened our opinion that the field of disaster analysis is not a coherent one, yet is emerging and will need time to maturate into a full-fledged academic field. In the meanwhile, however, the lack of consistency and communication between researchers has in fact caused a number of problems. Alexander (*ibid*) points to the following ones: in the modern world, death tolls have not fallen dramatically in response to improved mitigation; large-scale transfer of technology has not occurred, and more generally, disaster relief has not been adequately combined with mitigation and economic development. This is in particular true with respect to developing countries rather than developed ones, where these findings should receive a more nuanced interpretation. However, the threat of high victim tolls is still present in modern economies, where advanced defence measures often have created a feeling of false security, thereby stimulating the inflow of economic assets as well as inhabitants to the hazard prone areas. Examples are the inhabitants of New Orleans, ‘unexpectedly’ hit by hurricane Katrina; and the high damage potential (both human and economic) in the Western parts of the Netherlands, where polders reach a depth of 5 to 6 meter below the sea level, and flood standards are, in some places, set to as high as once in 10.000 years. These issues, in particular connected to the case of the Netherlands, will be addressed in detail in Chapters 7 and 8 of this thesis. We may see from the above that both theoretical and practical dimensions of disaster management have suffered because of a lack of development in the field. This thesis is an attempt to provide an *integrated analysis* and augment to the body of knowledge in disaster research, and in particular the studies of the economic consequences of major adversities, thereby focusing on those circumstances where *economic structure* and *size* or *scale* of the disaster meet.

1.2.2. What is the Problem?

There are at least three reasons, as we have just mentioned, to initiate research in the field of disaster analysis. However, there are many paths to follow, and one needs a certain lead to select a particular direction for an inquiry. For us, this lead was provided by the realisation that there was a fundamental problem at hand. This awareness was triggered by a project in which we were involved in the early stages of our work.

This research originated from a case study of the economic consequences of natural disasters in the framework of the Delft Cluster Project[3] *“Consequences of Flooding”*, under the research theme *“Risk due to flooding”* that was finished by July 2003 (see Delft Cluster Reports: Van der Veen *et al.*, 2003b; Roos and Roos *et al.*, 2003; Gautam and Van der Hoek, 2003; Reinders and Ham, 2003; Stuyt *et al.*, 2003; Asselman and Jonkman, 2003; Jonkman, 2003; Asselman and Heynert, 2003; Krom and Goovaerts, 2003; Galanti, 2003; Calle, Knoeff and Verheij, 2003; Van Mierlo *et al.*, 2003).[4] The project team, next to ourselves, included colleagues from the Public Works

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[3] Delft Cluster (DC) is a research cluster that includes six beta-institutes (Delft Technical University, TNO, Delft Hydraulics, Geo Delft, KIWA and UNESCO-IHE) advancing the knowledge and offering expertise in the issues that are found on the crux of nature, culture and infrastructure. The Cluster has six core research themes, namely, Soil and structure; Risk due to flooding; Urban infrastructure; Subsurface management; Integrated water resource management; and Technical knowledge management. More information can be found on the website of Delft Cluster, www.delftcluster.nl.

[4] These reports are also available online from http://www.library.tudelft.nl/delftcluster/.

Department, Ministry of Transport, Public Work and Water Management (Rijkswaterstaat), TU Delft, TNO Bouw, WL Delft Hydraulics, GeoDelft, Alterra, Delphiro and CSO. Various aspects of disaster consequences were studied; *inter alia*, the hydrological, environmental and geophysical ones, human loss, construction failure, and others. The task of the Twente group, in which the present author took part, was to outline a methodology for economic damage estimation and to provide a calculation of expected loss based on the hydraulic simulation of a hypothetical flood in the province of South Holland (we shall return to this study in Chapter 7). This meant, that already from the very beginning of the trajectory, alongside with getting acquainted with the literature in the field, we had to deal with empirics-related inquiries.

The assessment of expected damage figures on this hypothetical case was most revealing. The study illuminated that there was a lack of *common* methodological ground for economic damage assessment, which meant that a generally accepted interpretation of the disaster situation was not (yet) available. Being confronted with this, we decided to direct our efforts at the exploration of the issues in depth after the Delft Cluster Project was over. We started to look for ways to develop an *integrated* theoretical framework[5] capable of a consistent reflection of possible events and respective choices to be made at each stage of the disaster drama. This goal has determined the course of our further research.

The exploration of literature concerning economic consequences of natural disasters provided the definitive orientation of this research towards further methodological inquiry into economic damage estimation. This revealed a wide diversity of research in terms of models used, damage definitions applied, and purposes served. The existence of these differences across the studies certainly undermined the comparability, and in some cases, also the validity of results. Another point was the identification of 'weak spots' at which contemporary models fall short behind the research needs. The connection between the theoretical framework and empirical work was not always clear, especially in the representation of the spatial dimension of catastrophic events. The interpretation and application of theoretical concepts in empirical assessment varied greatly among various scholars (where a particularly severe situation appeared to have emerged around the conceptualisation of the concepts of 'direct' and 'indirect' loss), as well as transparency in model formulation was sometimes missing.

Simultaneously, we discovered that the need for in-depth research in the field of severe unscheduled events grows, fuelled by the rising awareness of societies about climate change and its possible implications. For example, Boorsma (2005), providing a reflection on the evolution of the modern welfare state under the conditions of climate change, greying of population and terrorism threats, warns about the unprecedented scale and pace at which those risks are developing. In fact, the search for answers seems to have resulted in a growing *gap* between the needs to solve the problem of major disasters and their consequences, and the insufficient capacity to tackle it.

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[5] A number of authors plea for integrative approaches in hazard management. For example, Hoekstra, (2005) claims that water management in the context of globalisation, climate change and increasing uncertainties cannot be considered as a subject of engineering solutions apart from the broader framework of sustainable development.

1.2.3. Our Vision

We decided to take a fresh look at the issues at hand, thereby necessarily abstracting from many specific aspects (to avoid too big scope at this level). We shall start from an interpretation of the *pre-disaster* situation in terms of the well-known economic circular flow concept. This, we believe, should provide the necessary benchmark position for further analysis. The need for analysis on the larger scale, like a region or a country, has dictated us the choice of the scope of our study with a focus on the meso-macro level of industrial activity. For this, the circular flow concept will be employed as a 'platform' through its notion of *uninterrupted* (circular) flow, which provides the backbone for studying the destruction brought about by a big disaster.

Subsequently, we interpret the economic *impact* of a catastrophe in terms of the *disruptions* of the pre-disaster circular flow.[6] These disruptions have a multitude of consequences. They mean, e.g., that expected final (consumption) demand will not be available. Other consequences are that those hoping for a job will not find employment, and, hence, will not receive a regular wage. So, parts of final consumer demand that have been produced will not find their hoped for buyers. Simultaneously, many of those who suffered a loss, will look for solutions to improve their situations. Finally, all these effects again have a momentum of their own, thereby laying claims on still available or accessible resources at an unprecedented scale (more about that later).

Thus, we shall look at the disaster's impact in terms of disruptions of the pre-disaster circular flow of goods and services. Therefore, we need to find a way of looking at the economy that can capture this notion satisfactorily. To this end, and perhaps surprisingly, we shall employ a model that stresses *interactions*; that is, circularity. This leads us to a search for frameworks that would be able to express the myriads of interconnections in a modern industrialized society including the 'translation' of these interconnections into 'products' like economic surplus and net output. This again leads us to a so-called inter-industry or input-output type of models where industries or sectors form the productive core. To be more precise, we arrive at a multi-sector type of model based on the *technological* properties of industries. That is, we will be looking at industries in terms of their production functions, and, more concretely, the way these production functions interlock. The technology 'in place' therefore provides much of the necessary structure to trace the pattern of physical disturbances that are at the hart of our exploration.

At the same time, we also shall look at what may be called social or institutional rigidities. These have not (yet) found a solid place within today's catastrophe literature. Yet, we feel that these are most important in interpreting the effects of a disaster. The term shall be used by us to distinguish specific regularities that play a dominant role in modern economies. One such rigidity concerns our level of consumption. In our modern societies, this level plays the role of a kind of anchor, in the sense that large fluctuations, possibly due to external circumstances, are to be avoided, even at large efforts. A similar role is played by the 'imperative' of employment. Keeping and restoring employment opportunities belongs to the most important tasks for nearly any government in a disaster's aftermath. In our modelling efforts, in the later Chapters, we shall repeatedly come back to this.

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[6] Clearly, this approach presupposes the existence of a well-established accounting system, that provides a good reflection of the actual economic activity.

We are facing other issues. As said, actually we shall be looking at disruptions, so at a *lack* of interrelations caused by the disaster. Here technology (thus) provides the core, and losses can be described in real terms. However, we also should be able to express 'costs' in a money terms. That is, we should be able to analyse the disruptions in terms of monetary flows. But then, how to think about 'disruptions'? Actually, we are entering an area that is thus far a partial *terra incognita*.

We shall also discuss economic models. These will be models of the meso-level, focusing on interactions at the industry and inter-industry levels. This choice is deliberate because both the macro-level, with its focus on the national aggregates, and the micro-level, with its focus in the individual person or agent, are not entirely appropriate to address questions of preparation for, and dealing with the risks of really big disasters. To that end, one most urgently needs a model type that enables the researcher to focus on what may be its most characteristic property, i.e. the disruption of existing interactions. To that end, a most important candidate family of models is provided by the now available input-output models. However, these models also have certain drawbacks. In fact, they are, despite their 'level', somewhat unlikely candidates.

The problem is that much of modern input-output analysis deals with impact studies in so-called *open* input-output models. This type of model is an excellent vehicle for determining the ultimate effects of changes in consumer demand on employment, imports, and other affected categories. The 'bridge' is provided by reasonably stable patterns in inter-sector or interindustry trade. So, in the standard approach we rather are looking at 'interaction', not 'disruption'. As we shall show, to study disruptions in the industrial networks, we shall have to go back to the basic building block, the sector's production function. As we shall see, this will provide a means to analyse the changes in inter-sectoral trade as a consequence of the catastrophe. Interestingly, to study disruptions, we shall go back to very early input-output forms introduced by Wassily Leontief in the 1930s, the so-called *closed* ones (Leontief, 1936, 1937). The closed models in particular stress man's dependence on the entire economy in producing his consumption basket and, most importantly, in providing the desired jobs. In our view, closed models are better in bringing to the fore the many dependencies that exist in modern economies. Unfortunately, the now available theoretical apparatus is not very developed. This is the reason why we devote much attention to this issue building up our model in Chapter 6. In fact, we start from the open model, but for the adapted input-output disequilibrium transformation that we offer, we essentially 'close' the system.

Disruptions or imbalances, when interpreted in terms of stable proportions, may be seen in way that some goods are overproduced while others are underproduced. There literally is no balance anymore in the economy in the sense that quantities demanded equal quantities supplied. We even may have to ask if previously existing productive activities are still there. This actually points at a different problem to address, and to a different model tradition. (We recall that the Leontief input-output model informs us about the outputs needed to produce a specific 'surplus', i.e. final demand. It does not have the possibility to inform us about disproportions in the light of a specific societal goal). Actually, there is an alternative approach, going back to Von Neumann (1945/46) that has a different philosophy, although the basic ideas were put forward already in the 1920s and '30s. Von Neumann was the first to deal with growth problems in a multi-sector setting. He thereby focused on one very special type of growth, i.e. balanced or proportional growth throughout the economy, that is, a case where all industries grow at the *same* rate. Von Neumann showed that normally there exists one particular uniform growth rate. What makes his approach interesting for us is that he, concentrating on finding the right inter-sectoral proportions for balanced growth, also showed that, in the light of this particular goal, some industries become superfluous in the sense that their products are not needed in the produced amounts. This implies that these industries may oversupply, and that their products, now redundant past a certain quantity, will receive a price zero. Stated somewhat differently, most importantly, we can also derive that certain industries are the real bottlenecks to growth, which is the other side of the 'overproduction' coin. That is, the overall growth rate could be higher if their output could be increased.

There is an interesting methodological background underlying Von Neumann approach. This goes back to a view put forward by Schlesinger at the mathematical Seminar conducted in Vienna in the early 1930s. Koopmans (1951, pp1-2) mentions that Schlesinger formulated a suggestion, also made by Zeuthen, that economic theory should not only explain nonnegative prices and quantities, but should also explain which goods are scarce and which are free (many earlier had concentrated on systems of equations which should produce the desired nonnegative outcomes for quantities and prices). Von Neumann accomplished a quite different task. He introduced alternative methods of producing a specific good, and allowed for joint production. He obtained statements on goods (which are free and which are not), but also on the available technologies (which are used and which are not used). Also, he firmly established the notion of a circular flow as a situation where commodities are simultaneously inputs and outputs in an interconnected system of production relation. Because no outside inputs or resources were required for, the model became a closed one. In this sense, Von Neumann's model is quite different from Leontief's. Von Neumann's model has always been used to study expanding economies. Most interestingly, as we shall see, it can also be used for studying contracting economies, as in the case of economies that have experienced a severe blow, see also Kemeny, Morgenstern and Thompson (1956) and Morgenstern and Thompson (1976).[7]

Later on, in the late 1950s and the 1960s, the balanced growth model provided benchmark scenarios for growth studies employing the turnpike idea.[8] In those models, labour is treated just the same as all the other productive resources; i.e., it may either be oversupplied resulting in unemployment, or be undersupplied acting as a bottleneck. This aspect seems to be of particular use for us in economic disaster analysis, where people, treated here as a production factor, and (distorted) employment opportunities in the immediate calamity aftermath may not match. This means that human resources are not used to their utmost because of unavailability of jobs, in turn implying that those without jobs do not have the means to sustain themselves; both are a problem and need a solution.

The multi-sector models we shall discuss are known for their 'rigidity'. That is, the production functions are of the so-called limitational type. One property of such functions is that price changes do not induce substitutions between input categories; the technology is fixed, unlike technology in neo-classical production functions. (So, if an industry wants to react on price changes, it has to adopt an alternative technology, which then –hopefully- is available).

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[7] Seed also Chacko (1976) for additional detail on the historical background of Von Neumann's model.

[8] The turnpike theories of the 1960s and 1970s discussed so-called fastest routes towards goals such as reaching full employment, increasing consumption per head or a better distribution of incomes; see e.g. Tsukui and Murakami (1979)

However, next to technological rigidities, there also are what we shall call '*institutional rigidities*'. We shall give these an interpretation somewhat different from the well-known organizational or governance rigidities such as analyzed in the New Institutional Economics (see e.g. Williamson, 2000; Menard and Shirley, 2005, and many others). In fact, we shall stay rather close to the models at hand. The background of our decision to introduce this wider type of rigidities is given by motivation that if we think about disaster and recovery, we must take into account that labour and industries are quite different in terms of their pre- and post-disaster characteristics. Labour is, in a sense, much more mobile than most industries can be. In cases where sufficient warning time is available, labour often has survived to an amazing extent. However, we shall focus below on two aspects that are dominant factors in any economy. The first one is that households' consumption demand remains remarkably constant over the years. Following neo-classical economic theory reasoning, this can be seen as consumers, having chosen a basket of goods that maximises their utility, keep consuming it. Keeping this in mind shall be a determining factor in our research. The other factor concerns the 'dogma' of full employment. Whichever vicissitudes an economy may suffer, full employment always is at the top of its priorities. Later on in this thesis, these two factors will be the determining elements for the post-disaster recovery trajectory. (In this sense, it replaces Von Neumann's proportional growth objective). In model terms, this leads us to a model that is 'intermediate' between Leontief and Von Neumann. With its help, we arrive at the novel concept of the *Basic Equation* in Chapter 6, which brings together the post-disaster bottlenecks.

There is one more important methodological point that we should mention at this point. As observed by several authors in the disaster community, input-output modelling makes it possible to look at the 'inside' of the complex inter-industry linkages within an economic system.[9] In this thesis, we shall expand this notion in, what we perceive, is a novel direction. We should recall that the information in an input-output table is based on *localised* production and consumption activities. That is, the flow and stock data are aggregation totals based on the compilation of individual establishments. We shall employ this property to describe the impact of a disaster. To this end, we introduce certain adjustments to the basic model to capture the complex disaster and reconstruction scenarios, thereby taking account of *changes* in the internal structure of the economy and its external links. In fact, we shall put forth a *modified* input-output framework which is, as we shall explain, specifically suited for disaster analysis and what may be called 'disequilibrium accounting'. Furthermore, it can be used as a starting point for projections in recovery scenarios and the modelling of precautionary measures and policies.

Many issues will be dealt with 'along the way'. As seen, we stress *physical* disruptions. But what about economic costs?[10] We shall emphasise that it is important to define clearly what is meant by 'economic costs' and how they are measured. Essentially, two types of costs are met in the literature, *direct* and *indirect* losses. Broadly defined, direct losses refer to physical damages to property and assets, and associated losses of circular flow, stemming directly from the 'interaction' with hazard.

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[9] See, for example, Cole, Pantoja and Razak (1993), Jones (1997), Shinozuka, Rose and Eguchi (1998), Okuyama, Hewings and Sonis (2002).

[10] In the scope of this thesis, we choose to focus on the economic side of disasters, and especially on the economic costs in terms of interruptions of economic flow. We explicitly abstain from addressing other dimensions of disasters connected, *inter alia*, to the loss of human lives, the valuation of assets that have cultural or historical value, or other non-market assets.

Indirect losses are, in turn, often connected to interruptions of business operations throughout the economy. This implies also, that while direct calamity consequences are often a matter of measurement, indirect losses require more than that; namely, some inference into the processes of disruption and recovery. In addition, a number of other essential elements comes to the fore in the discussion of disaster losses, which are connected to the choice of perspective, be it financial or economic; and the choice of the valuation method. To keep the appraisal of losses associated with a disaster consistent, one should also exercise caution with regard to what is in the literature referred to as 'double-counting' (we shall extensively discuss these issues in Chapters 2 and 3). Effectively, this concerns the awareness of the fact that assets, involved in production activities, can be measured either as stock, or as flow. Essentially, with the exploitation of stocks, flows are produced. For example, machinery and equipment are stocks; at the same time, when used in production processes, they give rise to the flow of new goods. If such capital assets are accounted as lost based on their stock value (e.g., replacement value), then the flow of goods that will not be produced by them are already taken account of. This implies, that counting both the stock and the flow values of the same asset means counting it twice. Finally, time aspect of costs should be considered explicitly. While in the immediate disaster aftermath only direct physical losses are observed, in the medium run indirect losses from business interruption surface. Because we select to have the pre-disaster development path as a threshold to which the losses should be related, we shall propose that costs of a calamity may be defined depending on the trajectory the economy will (or wishes to) follow after the catastrophe. This, evidently, makes planning in the form of contingent scenarios essential. Other issues concern the time aspect, and the role of typical dynamic modelling. Finally, we should stress that we make a distinction between types of emergency assistance such as personal aid and assistance, clearing debris, *et cetera*; and the systematic recovery efforts. We basically shall only look at the latter.

1.3. RESEARCH DESIGN

1.3.1. The Scope

A number of *choices* had to be made when we were setting the agenda for our research.

First of all, in this thesis we are focusing on the exploration of the effects of *major* disasters. These are significantly less studied than smaller or 'marginal' shocks. The key difference between the two is that, under normal circumstances, impact analysis is the usual instrument to discuss 'minor changes', i.e. disruptions that do not endanger the stability of the system. Large-scale adversities, on the other hand, impose disequilibrium and structural change and affect an economy in its entirety, where *ceteris paribus* assumptions are almost impossible. This means that major disaster analysis requires a new kind of models to investigate the nature of the processes behind efforts to achieve a new equilibrium. We shall concentrate on such approaches.

The **next** choice that had to be made is the context in which disasters and their consequences can be studied. Clearly, many aspects can be considered and many paths can be followed. Among these are the economic, political, social, sociological, environmental, ecological, cultural or psychological aspects of calamities. Because these problems have many aspects, it is impossible to cover all of them in detail within the scope of one manuscript. For this reason, we choose to narrow our research to the study of one particular dimension of disasters, namely, their *economic consequences.*

Third, it appeared that disasters have very different economic consequences in developed and developing countries (which we will address in more detail in Chapter 3). This may imply that different modelling frameworks have to be employed for each particular type of analysis. Considering this difference, we have opted for the exploration of impacts in the modern, *heavily industrialised societies* rather than in the less developed economies. Considering the complexity of modern industrialised networks, we decided to focus on the effects that an adverse outside shock may bring, disturbing the established balances and links within those networks.

Fourth, disaster analysis may serve different purposes, ranging from implications for national policy-making to raising the awareness of individual risk perception. However, it appeared that many studies are to a high degree *ad hoc* made with different conceptualisations of the term 'damage'. A conceptually generalised methodology seemed to be the missing link between the empirical examination of consequences of real disasters and policy advice. Filling this gap, with a very diverse literature at hand, turned into a challenge at large. However, we decided to direct our efforts at the quest for a better, more coherent and more general *methodology*, putting it at the core of our research. Therefore, this study has obtained a theoretical-methodological focus.

Fifth, the study of the literature on disaster analysis has shown a great *variety* of research at several levels. Often studies are looking into the effects of an adversity on the micro level, i.e. the economic consequences for particular businesses or groups of people. We should not underestimate the value of these inferences; notwithstanding that, it was found that studies of the effects on the economy-wide level are substantially underrepresented. This means that little is known of the loss of interconnections and links between the economic agents at large, which is in particular essential for getting insight into the consequences of major calamities. With this in mind, we have decided to direct our inquiry on the analysis of the linkages and relationships within the economy at the national level.

Finally, the *origin* and *nature* of disasters, be they man-made or natural, are essentially of little difference for our investigation. In the current inquiry we opt for inquiries into the substantial disruptions brought into an economic system by a hazard without particular reference to causality. We should point out, of course, that the nature of a calamity determines the character of disturbance to a great extent (like damage caused by flash floods would be different from an earthquake, a drought, an outbreak of a pandemics or a nuclear explosion). However, in the context of this study we shall not pay specific attention to the origin of a disaster. Nevertheless, because our case study is situated in the Netherlands and deals with large-scale flooding, for convenience sake we shall make reference to natural disasters[11], though our findings and methodology have broader applicability.

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[11] For more insight into man-made or 'manufactured' risks in the context of modern societies as opposed to external risks (natural hazards), one may consult the works on risk society, for example, by Ulrich Beck (1992) and Anthony Giddens (1990, 1999).

1.3.2. The Approach

The **goal** of the current inquiry is thus:

> *To develop a methodologically consistent framework with a good grasp of the complexity of connections within an industrialised economic network; suitable for the reflection and analysis of the economic consequences of a severe disaster; and which may also be used as a tool for policy analysis of both pre-disaster precautionary measures and post-disaster actions directed at targeted reconstruction and recovery.*

The goal as it is formulated above contains three elements that are at the core of our investigation: the reflection of actual processes in the wake of an adversity; modelling the consequences of an adversity, and the policy dimension. In order to achieve this goal, **research questions** were formulated providing structure to the inquiry. The following questions and sub-questions were identified:

1. What is the essence of a disaster in a contemporary economy?
   (Chapters 2 and 3)
   a. How can we define a disaster?
   b. Which concepts are essential to describe a disaster phenomenon?
   c. What kinds of economic effects of disasters can be identified?

2. In how far is it possible to model the impact of a disaster in an economy as a complex interrelated system in a consistent way?
   (Chapters 4, 5 and 6)

3. How can meso-level economic modelling help understand the way modern economies may deal with disasters?
   (Chapters 6 and 7)

4. How can this methodology contribute to the formulation of the role of policy in addressing disaster consequences and preparedness to those in modern industrialised economies?
   (Chapter 8)
   a. To what degree can disasters in contemporary societies be prevented?
   b. In how far can contemporary societies prepare to a disaster and how?

The above questions raise an array of fundamental issues not yet well covered in the respective literature. Another set of issues concerns methodological aspects of modelling economic consequences of a calamity. Here, structure and transparency are sometimes missing. Lastly, we are also touching upon the issues connected to economic policy-making. From an economic perspective, we are mostly interested in the analysis of actions and measures, their suitability with respect to the purposes served, and the identification of such economically grounded purposes.

To address the research questions, we need to establish a suitable framework, a *model*, in order to be able to incorporate various elements of disaster analysis we would like to study.

We are of the opinion that disasters are complex phenomena that in fact consist of multiple processes. This implies that we may analytically divide those processes into a number of stages. Applied to modelling, essentially, such an approach based on a multi-step procedure should make an analysis of economic system performance after a shock more transparent and controllable. We suggest one of the ways one may think about major catastrophes and their consequences (see *inter alia* Steenge and Bočkarjova, 2007). These can be considered the building blocks of what can be deemed as a novel approach in economic disaster analysis. Ultimately, a three-stage procedure is proposed. The first step is to get a proper perspective on the nature of the economic disruptions brought about by a hazard. Here it is important to pay attention to the emerging market disequilibrium and mismatches in the disrupted economic network. The second stage consists of addressing the post-disaster imbalances and a systematic investigation of the options open to an economy when entering the post-disaster period. Multiple paths can be followed; the challenge is to identify and model those of them that are most likely to happen or are most preferred. During the third stage, a special type of cost-benefit analysis of various *ex-ante* policy measures is suggested, based on the geographical dimension of the catastrophe. We envisage that precautionary measures, if taken, impose costs; at the same time expectedly they should offer better protection or reduced losses as a gain. On basis of respective costs and benefits of various measures, their feasibility can be analysed.

For the projections in the future development possibilities and processes with the prevalence of uncertainty[12], *scenario analysis* becomes a way out to analyse at least a number of selected trajectories. The essence and usefulness of scenario approach in disaster analysis is apparent: by formulating scenarios, those variables that are essentially exogenous can be endogenised, thus generating valuable inferences in the possible aftermath processes. The art of formulating scenarios is hidden in two boxes: first (following Duchin, 2006), formulate fruitful hypotheses leading to meaningful and ingenious inferences; and second (following Fontela and Rueda-Cantouche, 2004), translate the narrative of a scenario into the appropriate variables or parameters comprising a particular model. If the researcher is successful in applying this approach, it adds to the development and testing of a theory the additional dimension of exploration of future option and their systematic interpretation, being a noteworthy tool for policy advice and action planning. With this, the circle of theoretical analysis, future simulation and decision-making support is complete.

So, recapitulating: we have observed a great variety in approaches at disaster-related studies. In our view, there is a need for common ground and integration to bring the existing notions and concepts under one unifying roof. Particularly urgent is the situation where a very big catastrophe, natural or manmade, hits a highly developed

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[12] Here, we might find a parallel with the famous distinction that Frank Knight, made between 'risk' (which refers to situations where the probability of an outcome can be quantified by means of known probabilities) on the one hand, and 'uncertainty' (where the outcome cannot be quantified via a known probability) on the other hand (Knight, 1921). In line with that, we would propose that, strictly speaking, major disasters, as we discuss them in this thesis, are better described by uncertainty than by risk. Yet, in the later chapters (see Chapter 8), we shall present an approach that attempts at quantifying those uncertainties in terms of probability.

industrial nation. It appeared that many, often divergent, opinions exist. This is a situation that should not be accepted and should be addressed as soon as possible.

We shall advocate the need for a general methodological 'platform'. In this study that is provided by the notion of the circular flow. The catastrophe's impact then is modelled in terms of disruptions of this circular flow, which causes imbalances in production and consumption. Given an objective in terms of where the economy should after the disaster, recovery and reconstruction programs can start. We shall present a novel type of inter-industry model that focuses on the imbalances and disproportions.

We would like to stress that we are not aiming at providing a totally new foundation for the construction of the disaster analysis field. Rather, we will make an attempt to contribute to improving conceptual coherence in the emerging field. We thus are not aiming at providing an all-inclusive analysis of a disaster outbreak; instead, we have chosen to study one of the elements pertaining disaster analysis, placing it in the more general context of disaster policy and management. From a methodological point of view, we also are not aiming at presenting the 'best' model to analyse disaster consequences; rather, we wish to suggest a general framework as one of the ways for transparent and consistent analysis of disaster economic impacts within a complex modern industrialised economy.

1.3.3. Outline of the Thesis

Part I, Concepts, starts with two conceptual Chapters. Chapter 2 describes the core concepts in disaster analysis. We attempt to settle the definitions that describe the disaster phenomena in the economic context of our research. These are followed by the notions connected to the coping capacity of a system in response to a calamity. These terms are central to the analysis of system's vulnerability and resilience. They are indispensable in the new type of thinking about major tribulations in modern economies, as they specifically describe the attributes of the disturbed system. We also clarify the use and applicability in disaster analysis of related concepts of susceptibility, resistance, robustness, redundancy and sustainability. Policy-related notions of adaptability and mitigation are described in this Chapter as well, with the focus on the difference between the two, namely the system-oriented adaptability, and hazard-oriented mitigation.

Chapter 3 follows this discussion with the debate around another set of concepts connected to the analysis of the consequences of major adversities. Attention here is drawn to the differential impact of disasters. First, in terms of scale, it is important to distinguish between minor shocks, and major shocks to which disasters belong. The character of the impact of these two types of shocks determines the scale, and thereby also the approach to be taken to analyse these impacts. In the case of a major calamity we have to do with severe displacements in the established economic network. The second difference is determined in terms of the type of economy affected. It is proposed that developing and industrialised countries bear different kinds of burden as a result of a major hazard. We complete the Chapter discussing the concept of economic damage. We argue that the precise definition of damage hinges on a number of considerations, where choices have to be made. The first concerns the purpose, which damage assessment is intended to serve; the economic and financial appraisals being the major issue of choice. Second, the spatial and temporal dimensions of damage have to be considered before the analysis is launched. Finally, to avoid confusion in the application of damage concepts in empirical studies, one has to be aware of the measure of asset value used in the study. Thinking in terms of stocks and flows proves to be an excellent guide. We conclude with providing the definitions for direct and indirect economic damage.

Three Chapters comprising **Part II**, Building a disaster model, focus on the discussion of models and modelling in and for disaster analysis. In Chapter 4 we provide a review of selected literature dealing with modelling of economic effects of major calamities. Here we concentrate on the difference between measurement and inference. The former, in terms of direct physical damage, can be observed and measured directly; the latter – in the form of indirect economic damage – is much more difficult to grasp, though. This means, that modelling is needed to get insight into the interruption of production and consumption activities within an established economic network. In the light of this distinction, we review Dutch modelling schools, as well as internationally known approaches. We conclude with a discussion of the choice of the model, putting forward that input-output approach should prove especially useful in the analysis of economic structure on a grand scale, but should be adjusted for the modelling of major disruptions brought about by a hazard.

Chapter 5 contains the outline of the standard Input-Output model describing the interrelationships within an economic system with a short historical retrospect and basic model formulation. Given the particular ends our inquiry is serving, the analysis of major shocks, we provide a critical review of the characteristics the model possesses to be adjusted paving the way to our adapted analysis.

Chapter 6 forms the core of our investigation. We start with the outline of three issues central to the theme of disaster modelling intertwined in input-output approaches: the size or scale, the presence of rigidities, and policy issues present in disaster management. All of these have to be incorporated in ‘disequilibrium’ modelling of disasters. We continue with the brief literature overview on the existing models in input-output circles preceding our efforts on the construction of a framework viable of reflecting major disturbance. In particular, the so-called Event Matrix attracted our attention attempting to structure thinking around a shock and its aftermath. After presenting our assumptions, we set off for the modelling journey in the disaster-adjusted input-output world. From the very outset, we decide to split the analysis into three stages: immediate post-disaster situation, recovery stage and analysis of prevention strategies. For the first stage, we derive what we call the ‘Basic equation’ as a reflection of imbalances within an economy immediately after a shock. This is also the starting point for stage two, when recovery paths are modelled bringing the system to a new equilibrium. Multiple paths are possible; therefore scenario analysis is chosen as a tool to deal with the uncertainty. Finally, the building blocks of a sort of cost-benefit analysis of preventive or precautionary measures are presented. The elements of vulnerability, resilience, adaptation and mitigation are incorporated in the modelling as it is presented in this Chapter. The built up scheme is accompanied by small examples.

The Analysis part, **Part III** of this thesis, consists of three Chapters, two of which are devoted to case studies, and the conclusion Chapter. We begin with an illustrative calculation of industrial loss due to flooding in the Central Holland in Chapter 7. This case is based on the hypothetical (yet possible) simulation of a dike breach near

Rotterdam resulting in a major flooding. Essentially, this is the data from Delft Cluster project (see Section 1.2.2), the case we have started building our preliminary model from, and with which we would like to compare the estimates made with the improved methodology.

In Chapter 8, we continue the analysis, now drawing an explicit link between the economic analysis of disaster consequences in general and our proposed model in particular, and policy-making. Effectively, we argue that the economic component is indispensable for decision-making about such a complex issue as water management and flood protection in the Netherlands. Fortunately, this seems to become more and more common practice, though the transition from dominantly engineering solutions to a more integrated decision-making involving multiple parties is yet in process. We stress that this is an important development, especially provided the shifting attention in flood protection philosophy from probability management to risk management, where the latter is a product of probability and effect.

In Chapter 9 we conclude the thesis with a summary, main findings and contributions, and further research agenda. We provide a general reflection on the model we have developed, placing it in the broad perspective. We point at the role that our proposed model may play in the light of developments taking place in disaster analysis and policy practice. We also provide some closing remarks on the limitations and issues that may become potential topics for future inquiries or a follow up of this thesis. One of those is found in gaining additional insight in theories emphasising the prominent role of space, like the New Economic Geography theory; another possibility accompany theories explaining policy change, like political economy. Many other aspects connected to disaster phenomenon were outside the scope of the current study. However, we suggest that the road to more integrative, including inter-disciplinary, approaches should be followed also in future work. We conclude with suggestions for further research.

Part One

Conceptual Issues

Chapter 2

Core Concepts in Disaster Analysis

2.1. INTRODUCTION

In this chapter we intend to contribute to the debate on the fundamental concepts in the field of disaster analysis is an open one. We shall attempt to clarify selected issues and work towards consensus on basic concepts such as disaster and catastrophe, as well as related concepts of vulnerability, resilience and adaptability. What is the essence of a disaster? Do we mean an economic or natural disaster? Is there a difference between a disaster and a catastrophe? What are economic vulnerability and resilience? Are all these mere ‘buzz’ words, or are they meaningful terms? In the coming Sections we shall address these questions.

The purpose of identifying and providing a shape for the core concepts in economic disaster analysis can be found in the need to gain more insight into the nature of a disaster in modern economies, to deepen the understanding of the processes behind it, improve explicability by modelling; and ultimately being able to articulate the results and findings to the broad audiences inside and outside the scientific community. A well-defined conceptual base will be the initial step in building our integrative approach to disaster modelling.

2.2. WHAT IS A DISASTER?

It is considered to be true that natural disasters mostly erupt spontaneously or at very short notice. Therefore people are often caught by surprise when a calamity occurs. Usually little can be done to prevent or reduce the magnitude of a natural phenomenon. Nature and the extent of the impact of natural disasters on human society (number of deaths, structural damage, insurance costs, *et cetera*) do not depend solely on the characteristics of the event itself, e.g. a storm path or strength of an earthquake. Other factors can prove to be equally significant: for example, the proximity of populated areas, disaster-proof constructions and infrastructure, the ability of individuals and businesses to respond and adjust to a calamity. Following Cole (1998) earthquakes and flash floods, mass movements, mud and snow avalanches, cold- and heat waves, tidal waves, droughts, volcanic eruptions, storms and tornadoes “are natural occurrences. In contrast, damage caused […] can always be traced back to human activities. By setting in flood valleys man has put himself – consciously or unconsciously – at the mercy of flood risks.” Therefore, it is more the interaction between the natural occurrence and human induced systems, which leads to a disaster.

Tsunamis, floods, droughts, hurricanes and earthquakes seem to have become a constant threat to contemporary societies. In the past decades we have seen a growing awareness of the devastating effects of these natural disasters on the economies of developing and developed countries. The World Bank, the United Nations and the European Union have published a number of reports on this problem, *inter alia* ECLAC (1991, 2003), UN/ISDR (2002), Colombo and Vetere Arellano (2002), Freeman *et al.* (2004), Arnold (2006). Parallel to this awareness we note a strong increase in the interest in the methodology of estimating economic consequences of disasters on current and future welfare of modern societies.

Calamities appear to be of a dimension we hardly experience regularly; yet, more and more frequently, the terms ‘disasters’ or ‘catastrophes’ are used. However, these concepts are rarely defined precisely. This means that, on the one hand, contemporary societies more often face exceptional events of unusual strength and consequence, and have to find ways of dealing with them. This implies that a new problem is now facing the world, which needs to be solved urgently. On the other hand, there is yet no enough insight into the nature of these calamities and their potential impacts. Some ten years ago Alexander (1997, p.298) remarked: “there has been a general lack of holistic analyses that treat hazard, risk and disaster as integrated phenomena. Many links between the various aspects of them remain poorly understood.” This is still largely so; at present there is not enough adequate scientific knowledge on the issues of disaster vulnerability, response and preparedness. We shall start by identifying the essence of disasters in the context of our research.

We will recall that disaster analysis, and especially its economic dimension, is a relatively new field of study. Alexander (*ibid*, p.289) makes the following observation on this: “as befits a field in which the social is combined with the physical, and in which some 30 different academic disciplines have a hand, most concepts associated with natural disaster lack fixed definitions, as they are used by practitioners with very diverse objectives and perceptions.” Quarantelli (1995) follows this argument by stating that the field cannot develop properly as a research enterprise unless there is more clarity and consensus on the central concepts in the field. That is why, in approaching the issue of *major* disturbances we shall first try, for clarity’s sake, to establish the definition of a disaster to be used within the scope of this thesis. Alongside the concept of disaster, we shall come across a number of other terms often used in calamity analysis, concerning the nature and scale of the event, the coping capacity of the system in response to it, and the ability of a system to adjust to a future possible calamity. In the course of this Chapter, we shall cover them as well.

2.2.1. The Concept of Disaster

In general terms, catastrophes that may have disastrous effects, can be usually categorised as being of natural or man-made origin (UN/ISDR, 2002). Natural phenomena that can pose threats to humans can be extreme weather events, earthquakes, floods, droughts, storms, tropical cyclones and hurricanes, wildfire, tsunami, volcanic eruptions and avalanches, as well as epidemic diseases, plant or animal contagion and intensive infestations. Man-made calamities can range from technological disasters, such as industrial pollution, nuclear power station failure and radioactivity, toxic waste and dam failure; to terrorist attacks. Nowadays, it seems both categories of calamities are increasing. First, the climate change research (International Panel on Climate Change, IPCC, 2001 and 2007; and World Wildlife Foundation, WWF, 2004) proclaims substantial shifts in the global climate, increasing sea levels and average temperatures, leading to unpredicted changes in weather and the increase in number of extreme events. Furthermore, in the past decades, man-made disasters and the threat of terrorism in particular, are experienced all over the world. This has posed a new, until now unknown danger, where the coping capacity of nations in response to these challenges has become of critical importance.

Let us first of all consider the terms *’catastrophe’* and *’disaster’*. Although ’catastrophe’ is frequently used alongside ’disaster’, it is not a well-defined term, being simply referred to as ‘unusually severe disaster’ (Wikipedia). For this purpose, ‘disaster’ is a more familiar concept, referring in the first place to “the impact of a natural or man-made event that negatively affects life, property, livelihood or industry often resulting in permanent changes to human societies, ecosystems and environment”. UN/ISDR (2002, p.338) provides a similar definition, adding that “It results from the combination of hazard, conditions of vulnerability and insufficient capacity or measures to reduce the potential negative consequences of risk.” It is important to note that the *impact* or consequences are mentioned, not the event itself, which is called a disaster. In line with this, natural hazard, the term more commonly used in American literature, is the manifestation of disaster, exacerbating vulnerable conditions and exceeding individuals' and communities' means to survive and thrive. Quarantelli (2001, p.332) points out that it is not the natural phenomena alone, which lead to a disastrous impact, it is a combination of the extreme phenomena emerging in the nature and socio-economic system that, when enmeshed, can produce a destructive outcome. Alexander (1997, p.289) has a similar interpretation: “every natural disaster involves a unique pattern of physical energy expenditure and human reaction”. Furthermore, he adds (*ibid*): “there has been an increasing tendency to regard disasters as caused more by the social conditions they affect than by the geophysical agents that precipitate them”. In other words, hazard represents only the potential for causing damage (Benson and Twigg, 2004), following these authors, or the expectation of the effects of a natural phenomenon (FEMA, 1991). It is the interaction between a hazardous event and human-induced systems that makes this potential turn into a disaster. Moreover, Horlick-Jones (1995), Bankoff (2001) and Schipper and Pelling (2006) claim that, contrary to widespread views, disasters in modern societies are not natural, but rather social phenomena. Morrow (1999, p.1) from the sociological perspective, adds that “disaster vulnerability is socially constructed, i.e., it arises out of the social and economic circumstances of everyday living”. In other words, it can be said that disaster event only triggers those inherent vulnerabilities to surface and intensifies them in the face of survival. Dombrowsky (1995, p.241), who developed a sociological approach to disasters, is even more explicit in defining “disaster as an empirical falsification of human action, as proof of the incorrectness of human insight into both nature and culture”. Therefore, it takes two, the outside agent *and* the human-induced system, to make a disaster.

The abovementioned disaster definitions make a clear point that for the concept to gain its scientific contents, it has to be polished. Porfiriev (1995, p.285) discussing the methodological issues of definition and delineation of disaster, notes: “It is argued that there are two principle orientations or approaches to research, namely an applied/pragmatic one and a theoretical/conceptual one. These are based on ontological and epistemological grounds, respectively, which serve as the main factors determining the existing differences and variations in the studying and understanding of disasters." This may serve as a guiding principle for discussing the theme of disasters, explicitly marking the differences between applied and theoretical research. In his study of disasters, Gilbert (1995) summarises the theoretical approaches in literature. He crystallizes three broad paradigms: Firstly, disasters are seen as a duplication of war, where human communities are reacting globally against outside aggression. This partly contradicts Quarantelli (2001, p.335), who explicitly excludes social conflicts (such as wars, ethnic genocides, riots or civil strife, revolutions, terrorist attacks, acts of sabotage, *et cetera*) from the scope of disaster concept. Secondly, disasters are an expression of social vulnerabilities, inherent problems, which a society has to deal with. This presumption supports the point of view of Morrow (1999) to which we referred above. Thirdly, disasters are described as an entrance into a state of uncertainty, where the danger is difficult to define; it is apparent that it exists, yet its shape is elusive[13]. To some extent, in our opinion, disasters possess all three characteristics. Very often, it is an event stipulated by an external agent, which steers the society's practices away from their usual path. At the same time, the state of emergency can trigger the failure of the system's elements to perform because of their inherent faults. Finally, in the contemporary worlds of climate change, threats of terrorist attacks and technological advancement, we are dependent on the environment we live in. If this experiences a serious breach, whether natural, technological or human-induced, a disaster may deem unavoidable. Yet, the exact source and timing of an actual hazard remains uncertain.

Furthermore, we want to pay attention to the literature dealing with the economic aspects of disaster definition. Rose (2003) is one of the few authors attempting to provide an explicit economic dimension to the definition of a natural disaster. Rose is trying to ascertain whether, in economic terms, calamities should be seen as a separate unique event, as a representative of a type of events, or whether it depends on the event as soon as it adversely affects the economic performance of a country. Rose develops a typology, based on three groups of characteristics, i.e.:

> "First, are the ordinary physical characteristics of the natural, technological or political-economic stimulus (causal agent, areal extent, rate of onset, predictability and duration). Second, is the economic magnitude, or "effect", which really defines the disruption rather than the event that triggers it. Third, is "manageability", which is the buffer between physical characteristics and the effects in terms of society's ability to modify the disruption." (*ibid*, p.5)

The author concludes that research on economic disruptions based solely on causal agent, although it provides a substantial explanation, is too limited to explore the consequences of calamities in contemporary economies. Rose's insights have added the revealing categorisation of what he called urban disruptions, transitional disruptions and water-related disruptions.

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[13] Here, we may again refer to the well-known distinction of Knight between risk and uncertainty (Knight, 1921). In his view, risk refers to a situation where the probability of an outcome can be calculated. The reliability of the estimate depends on theoretical insight and stable empirical conditions. If the reliability is sufficiently high, this implies that one can insure oneself against the particular event. Uncertainty, on the other hand, refers to a situation where the probability of an event cannot be determined, and where the outcome cannot be insured against.

Besides, an interesting question is: What is the threshold in economic terms at which a natural hazard becomes a disaster? Various measuring scales for economic disasters can be found. For example, one of them is an operational tolerance level of 2% or greater output reduction in the economy affected (Rose, 2003). This might imply that hazardous events curtailing over 2% of production of the US would in economic terms be considered a major calamity. In this sense, hurricane Katrina does not apply to the US, but it definitely applies to the level of the state of Louisiana. Similarly, Katrina would be a national disaster, had it occurred in the Netherlands. According to Rose, due to the varying size of the economy in question and the time horizon chosen, the definition of a (economic) disaster becomes a relative concept. This interpretation immediately addresses the important issue of spatial dimension, which has to be included in disaster definition. Thus, when speaking of a disastrous event, one has to be explicit about the geographical area that is referred to when describing the effects of a calamity.

Apart from the relativity of the spatial dimension of the concept, the suggested output loss threshold can also be argued. In fact, Alexander (1997, p.290) summarises that elements that have been used to define disaster include the following four: number of deaths; value of damage and losses; impact upon the social system; and a geophysical definition (the latter, however, is discredited by some authors who consider disasters to be a pure social construct). Among authors who attempted to quantify a threshold for disaster, Smith (1996) offers an alternative measure, namely economic damage in excess of 1% GNP. Albala-Bertrand (2002) suggests that “a disaster impact is generally defined as major if estimated direct losses approach or exceed the average GDP growth rate of an affected country and/or damage seriously affects economic activity even if direct losses from the event are not a significant portion of GDP”. Bureau of Transport and Regional Economics (BTRE, 2001), Australia, however, offers an absolute total cost threshold of 10 million dollars to define a disaster. These last three quantifying definitions of a disaster are essentially based on the concept of losses, where economic damage, direct, indirect and total losses are mentioned. The explanation of these terms needs a special Chapter in itself, as various authors offer also varying definitions of the underlying concepts. We shall devote Chapter 3 to the discussion of damage and related concepts in disaster analysis, which our reader is also advised to consult.

The situation as above, where multiple points of reference exist, gives too wide space to interpretation of what a catastrophe or a disaster might be, leaving the concept vaguely defined. Bram, Haughwout and Orr (2004), conducting a study of economic effects of 9/11 terrorist attacks in New York, claim that “measuring the scale of a disaster is never easy”. Therefore, it would be wise to narrow the definition, and in doing so, we shall return to the foundations of the basic definition of a calamity. In the available descriptions, often ‘permanent changes’ in the affected systems, ‘change of an outstanding radical and rapid character’ or ‘serious disruption of the functioning of the community’, are referred to. All these expressions point to an extraordinary sort of negative impact that a system is experiencing. From that, one can derive two main features of a disaster: the shock is sudden or unexpected, and it is exceptionally strong. Gunderson (2003, p.35) in his studies of ecosystems is talking about “surprise – unexpected discrete events, [that cause] discontinuity in long-term trend”. At the same time, we recall that socio-economic scholars like Folke, Colding and Berkes (2003, p.359l) call crisis a special type of surprise. This sort of ‘surprise’ factor makes the systems enduring a disaster particularly vulnerable; the strength that the hazard hits with makes it almost unbearable. So, the definition of a disaster to be used within limits of this thesis is as follows:

> *A disaster is a discontinuity resulting from interaction between a natural phenomenon or a manmade failure, and a human-induced system, where the system becomes adversely affected beyond the scale of minor changes, implying loss of connectivity within the established system, with well-specified spatial and temporal dimensions.*

The definition of disaster as stated above implies a clear scale distinction on three levels: spatial, temporal and the strength of impact. Whereas the first two dimensions may essentially be left for determination within the framework of a particular study, the issue of disaster impact requires additional elaboration. In the following Section, we shall devote attention to this factor.

2.2.2. Disaster and Catastrophe: A Matter of Scale

We have pointed out in the previous Section that a catastrophe is "an unusually severe disaster". Although Rose (2006, p.28) would "offer no specific definition of the threshold at which a disaster becomes a catastrophe", he refers to the examples of the recent calamities, such as Hurricane Katrina (2005), the Indian Ocean Tsunami (2004) and the attacks on the World Trade Centre (2001). However, the following question arises when discussing the scale of a catastrophic event, namely: What exactly distinguishes a 'catastrophe' from a 'disaster', or any other sort of adverse shock?

Concerning disaster as a major external disturbance to an economy, we have to address developments that take place in the system in the disaster aftermath. In our investigation, we highlight the exploration of disaster effects in developed countries with well-established industrialised networks in contrast to those in developing countries (as also do Morrow, 1999; Shook, 1997). We shall return to this discussion in Chapter 3, Section 3.2.4 of this thesis. Following this line, we are thinking in the first instance in terms of interconnectedness on various levels between production sectors, markets, as well as individual agents, such as producers, consumers and government. Under normal conditions, markets for goods are driven by scarcity-abundance mechanisms, which determine prices. Some markets are connected through product substitutability and complimentarity, thus influencing prices. As we know from economic theory, prices are superior mechanisms triggering incentives – both to produce and to consume. This means that final product markets and intermediate product markets (via production processes) are interconnected in a circular flow. Individual consumers and governments, that make decisions to consume final products following their preferences, dictated by utility maximisation, affect prices and quantities, determining how much output should be produced. This, in turn, affects the demand for intermediate goods, and therefore also supply, and consequently the markets for intermediate goods, and so on. This is a simple representation of a circular flow of activity. Taking into account international trade as a part of economic modelling exercise will impose another layer of complexity and interconnectedness. Clearly, a real economic network reveales even a greater level of intricacy, from which it becomes apparent that a shock, brought about by a devastating natural phenomenon, may have serious consequences for almost each element comprising a system. Moreover, in a regulated economy, where market forces are not present on all markets, impact of a disturbance can be even more substantial, as not all markets can clear through the price mechanism.

In Chapter 1, we mentioned the difference between a marginal impact and a *major shock*, and made a choice in favour of analysis of severe disturbances, to which disasters belong. The essential point of difference is that under minor impulses, a robust economic system remains stable, as it is relatively quickly able to adjust and restore equilibrium. However, in the situation when a system undergoes a significant fluctuation affecting a complex economic network in the urbanised high-tech society, the effects are expected to be much more severe (Alexander, 1997). Also, the presence of the so-called rigidities plays a role here (we touch upon them in Chapter 3, Section 3.2.4). When a major shock is in place, a system cannot be described as robust, in a sense that it can instantaneously deal with a shock, and needs time to find its new destination again. This means, that we need *other concepts* that would be able to describe this situation. Besides, a major shock cannot be analysed as a sum of marginal ones, because the dislocation occurring to a system by severe tribulation is of a much higher order and has by far more reaching repercussions throughout an economy (Van der Veen, Vetere Arellano and Nordvik, 2003). The '*bigness*' of the event plays a major role, which is also pointed out by the investigators in the aftermath of hurricane Katrina (see, for example US House of Representatives, 2006), who observe (*ibid*, p.1): "a catastrophic disaster like Katrina can and did overwhelm most aspects of the system for an initial period of time." To further elaborate this point, it is the severity of a shock which plays the crucial role. When a calamity occurs, there is a point when established balances within the system become so disturbed, that its basic structure no longer resembles its features and returning to the pre-calamity state requires enormous resources not to be found within the system itself. Following Carpenter *et al.* (2001, p.778), who focus on resilience issues in ecosystems, "in this case, we think of perturbations as displacing the system from a particular configuration and the underlying structure as determining how the system will evolve after the displacement". This lends itself as a suitable point to draw the line between a 'disaster' and a 'catastrophe'. A disaster is a substantial adverse shock to an economy which is however found before the collapse point, while the system is still able to maintain its basic structure and its operation, though partially hampered. A catastrophe, on the other hand, can be characterised, in its extreme, by evidence of system failure on its various levels.

This means that we are dealing with some threshold level of persistence that a system can endure before it collapses under an impact, and this point marks the boundary between an 'ordinary' disaster and a catastrophe. This brings us to the next question of where this boundary is, which separates the system being able to recover its operation, and the system experiencing a failure, which is not able to resume operation without attracting outside resources. Carpenter *et al.* (2001) provide the answer to such a question, framing it in terms of resilience and resistance. They give an example, "two systems […] may have the same resilience, but differ in their resistance, as measured in terms of how much they are displaced (or disturbed) by a given physical force or pressure". So, according to Carpenter and colleagues, resilience is a system characteristic; whereas resistance is shock-dependent (our definitions of resilience and resistance are offered, respectively, in Sections 2.3.1 and 2.3.4). The interaction of the two determines the level of persistence of the system after a particular shock (*ibid*, p.779). This means, that the shock that jeopardises both the level of resilience and resistance (to which we shall return in the next Section), dooms the system to collapse. That’s when we suppose it should be called a catastrophe.

For clarity’s sake, a disaster can be referred to as a ’big shock’, conceptually distinguished from a marginal impact (Okuyama, 2003a, argues for development of the theory of economic disasters). At the same time, a catastrophe can be described as follows:

A catastrophe is an extremely severe adverse shock, which causes a substantial disruption of the system, with well-specified spatial and temporal dimensions, to the extent that it fails to perform its vital functions for a considerable period of time, or forever.

In this connection, disaster literature seems to deal with ’disasters’ as shocks that go beyond the conventional marginal analysis. The US National Research Council has similar findings (1999, p.40): “the abruptness, impermanence, and often unprecedented intensity of a natural disaster do not fit the (usual) event pattern upon which most regional economic models are based.” Provided the specific nature of major disturbances in particular in terms of the consequences of which remain as sources of potentially high threat to modern societies, we shall consider, in the scope of this thesis, both disaster and catastrophe events. For a while, we shall not look at the differences between the two; rather, we shall attempt at providing insight into the processes brought about by these severe calamities as an alternative to the conventional analyses of minor shocks. We refer to the latter, again, as such shocks, to which a system is robust in the sense that it can deal with them with ease and relatively fast, without incurring drastic changes in its structure.

2.3. DEFINING COPING CAPACITY IN RESPONSE TO A DISASTER

As we have seen above, in the analysis of economic system response to a major catastrophe, an entire collection of concepts such as vulnerability, resilience, adaptation, mitigation, as well as related notions come up to the surface. Definitely, we need more elaboration and clarity on these concepts. Recently, an observation was made among the economists active in disaster research (Bočkarjova, 2006) that there should be more consistency in using resilience, based on the fact that both the processes before, as well as after the outbreak of a disaster are described as resilience without mentioning the term; or the notion is widely used as a popular ‘buzz’ word, becoming effectively empty.

Alexander points out the importance of taking into account these new, emerging concepts in disaster analysis (Alexander, 1997, p.291): “Many influential writers have seen vulnerability as one of the keys to understanding disaster, because it is correlated with underprivilege, with past losses and with susceptibility to future losses”. The problem is, however, that neither multidisciplinary literature covering disaster modelling, nor economic literature in general, have developed widely accepted definitions of these concepts. In this Section we shall try to contribute to the debate on these important concepts, by attempting to clarify these matters. As outlined above, defining the scope of the concepts, on the one hand predetermines the borders of the analysis to be performed, requiring more specificity from the researcher; and on the other hand provides more insight for drawing inferences for policy directions.

2.3.1. Resilience and Adaptability in Disaster Analysis

Let us start with the concept of resilience, central to our analysis. It often surfaces in disaster studies, though not often its precise definition is provided, and its meaning varies depending on the context. The reason we chose to pay special attention to this concept is connected to the topic of our inquiry, namely, large-scale disturbances and their economic consequences. Indeed, specific nature of shocks we study, i.e. disasters or catastrophes, as defined in previous Sections, is fundamentally different from major studies that focus on what is often referred to as incremental or marginal impacts. The scale of major shocks, alternatively, triggers the occurrence of a different set of effects within an analysed system, and consequently requires a new mode of analysis. This, in turn, demands a new set of concepts characterising and describing the phenomena and the system undergoing major changes, necessary to uncover the processes behind a calamity. In this respect, resilience is the concept linking the event of a disaster and displacements in an economic network to the achievement of a new equilibrium state (as well as recovery to follow), the process often omitted in incremental or impact studies, as it is assumed to take place almost instantaneously through the working of economic (market) forces. Here, on the contrary, a system found out of balance occupies an important place in disaster analysis. The processes taking place at recovery stage, are not straightforward, and thus need closer exploration. Resilience, in our view, is a reliable guide in this inquiry.

It is of interest to observe the evolution of the resilience notion. Technically, the term ‘resilience’ originated in the field of ecology (Carpenter *et al.*, 2001, p.765). Green (2003, p.21) notes, however, that “as a concept, it has been translated from the material science […] into ecology [… where] the term has been shifted into systems theory and significantly widened to take account of multiple stability domains”. During this evolution, the original application of the notion of resilience to characterise individual features has also expanded into the analysis of system attributes. Besides, Denhardt (2005) mentions that the concept is more frequently used in medical, psychological and ecological studies, rather than in studies of organisations. We shall proceed with the discussion on this theme.

Starting, we shall provide a selection of views on resilience among the environmental scientists and (socio-)ecologists. We believe this would allow for a substantially deeper and richer exploration of backgrounds and ideas, which can ultimately be borrowed for concept definition in our disaster analysis. Gunderson and Holling (2001), the distinguished scholars in the field, define resilience as the capacity of a system to undergo disturbance and maintain its functions and controls. Alternatively, the key criterion of resistance, in their view, is persistence of the system, and therefore it is necessary to consider resistance (which is essentially a flexibility parameter) as the complimentary attribute of resilience (which the authors consider as an absolute measure). Carpenter *et al.* (2001, p.765), in turn, defines resistance in terms of magnitude of disturbance, which can be tolerated before a socio-ecological system moves to a different region of state controlled by a different set of processes. In contrast to Gunderson and Holling, Carpenter *et al.* place the concept of resilience as very similar to persistence. Also, they view resilience as a multidimensional concept, namely

> "…we must begin by clearly defining resilience in terms *of* what *to* what. These aspects change, depending on the temporal, social, and spatial scale at which the measurement is made. […] Just as resilience can be achieved in one time period at the expense of resilience in a succeeding period, resilience at one spatial extent can be subsidized from a broader scale. For example, it is common for a regional crisis—drought, say—to be relieved by the importation of resources from the state. The region persists, but only through external subsidy." (Carpenter *et al.*, 2001, p.767)

This interpretation of resilience explicitly requires clarity on the choice of temporal and spatial scales, which is a conventionally difficult task, leading to the issue of boundaries, which we already came across when discussing the concept of disaster in the previous Sections. The solution to these puzzles is the art of being consistent in defining various dimensions of the concepts used in the same study.

Another attempt for an elegant solution is provided by Allenby and Fink (2005, p.1034), where "resiliency is defined as the capability of a system to maintain its functions and structure in the face of internal and external change and to degrade gracefully when it must." However, the term 'degrade gracefully' remains vague, leaving broad room for interpretation. In this sense, the definition provided by the Resilience Alliance (2005), assembling efforts in the research on resilience in social-ecological systems, seems to provide a clear guidance encompassing a wide range of basic characteristics:

> "Resilience as applied to ecosystems, or to integrated systems of people and the natural environment, has three defining characteristics:
> 1) The amount of change the system can undergo and still retain the same controls on function and structure;
> 2) The degree to which the system is capable of self-organization;
> 3) The ability to build and increase the capacity for learning and adaptation."

This Resilience Alliance definition is also broad enough and can easily be applied in social sciences, in particular to the study of the survival of economic systems under the impact of an extreme negative shock.

The internet-based Wikipedia gives an adjusted definition of business resilience: "In business terms, resilience is the ability of an organization, resource, or structure to sustain the impact of a business interruption and recover and resume its operations to continue to provide minimum services". This definition, however, does not encompass the frequently incorporated element of learning and adapting often seen in the (socio-)ecological literature. We would nevertheless agree with the latter. In this connection, we once again refer to Gunderson (2003): "Adaptive capacity is a component of resilience that reflects the learning aspect of system behaviour in response to disturbance." Thus, talking about the resilience of a system, one should discuss its adaptability as well. In terms of disaster analysis this means that adaptability of a socio-economic system is an essential part of the whole process of 'living with the threat' of a disaster. The process of adaptation in advance to an unknown possible calamity includes building up resilience, meaning resilience as a process of learning and adjustments, rather than a state, adding to it a flavour of dynamics.

One other aspect of the resilience is whether it is a normative or an absolute notion. Carpenter *et al.* (2001) argue, “unlike sustainability, resilience can be desirable or undesirable […] In contrast, sustainability is an overarching goal that includes assumptions or preferences about which system states are desirable.” This is an interesting statement as, indeed, a system under stress can have inner resilience and bounce back responding to a shock; however, this may not necessarily result in a response which is desirable from the point of view of society. Instead, there are numerous ways how an (economic) system can cushion a disaster in any other way than expected by planners. Taking into account the notion of adaptability, which is included in the concept of resilience by Gunderson (2003), making it an ever-evolving process, it is important to consider resilience of a system in conjunction with sustainability goals. Provided the resilience is built up in line with the sustainable development trajectories, there is an increased chance that the system shall respond in a crisis situation in a way, which is most preferable.

2.3.2. The Economic Dimension of Coping Capacity

Among social science researchers, recently there is a growing urge to pay more attention to the concept of resilience. The increased frequency in using the term ‘resilience’, especially in disaster modelling and analysis, and the fact that this term in the past was unjustly disregarded, formulated the need for a more coordinated effort, also in the economics world. Rose (2004b) touches upon the issue of resilience, which is repeatedly coming to the surface in disaster literature. Taking into account a wider temporal span in disaster analysis, i.e. time necessary for recovery in the disaster aftermath, often taken as a part of impact analysis, resilience becomes an essential matter, as it has a direct bearing on the total damage sustained by an economic system. In relation to this, it can be assumed that a higher resilience level can make the economy recover faster and with fewer costs. We shall outline the trend in thinking about resilience among economists.

If we follow Parker, Green and Thompson (1987) three notions describe the coping capacity against major (economic) shocks: susceptibility, vulnerability or resilience, and adaptability. A number of inferences can be drawn from this classification. First, we note that the authors place a reciprocal link between resilience and vulnerability. However, we can argue that one does not exclude the other, and a system can be vulnerable to hazards, but at the same time also resilient in its response to a major disruption. This means that we would opt for vulnerability as a static, inherent feature of the system under attack, while viewing resilience as a dynamic characteristic of the system in action, responding to the shock. Secondly, the concept of resilience is clearly separated from ‘adaptability’, which is different from what we observe in ecological literature.

On the other hand, Green (2003, p.25) states that “the resilience of a system is: ‘the dynamic response of vulnerability over time to the perturbations to which the system is subjected.’” With this, Green points to the static character of vulnerability and the dynamic character of resilience, as we suggested above. Furthermore, Green (*ibid*) proposes that “a resilient system is then one which bends under stress but does not break, and which returns to a desirable state after the perturbation has passed”. This statement on the one hand clearly suggests that resilience is a post-disaster category; and on the other hand assigns the positive character to resilience, assuming that its resemblance should result in a system coming back to a desirable state. Rose (2006) also complies with the latter. We disagree with Green and Rose in this respect, but would rather take the position of Carpenter *et al.*, that resilience without being coupled to the concept of sustainability is context-free, and targeting resilience alone can lead to an outcome which may be different from the desirable state of recovery.

Rose (2004a, 2006) provides an analysis of resilience covered in economic literature on disaster analysis and opposes the view that resilience encompasses a portion of pre-disaster adaptive capacity. He claims that resilience is purely a post-catastrophe feature, characterising the "inherent and adaptive responses[14] to hazards that enable individuals and communities to avoid some potential losses". Rose clarifies, "in contrast to pre-event character of mitigation, economic resilience emphasises ingenuity and resourcefulness applied during and after the event". The author makes an apparent distinction between the pre-disaster mitigation activities directed at decreasing the probability of the catastrophic event to occur, and the post-disaster adjustment of an economy, characterised by resilience. It is important to mention that in American literature, mitigation is usually referred to any pre-disaster preparedness measures; while we would suggest distinguishing between two types of *ex-ante* measures, mitigative and adaptive, both of which can be important in terms of decision-making. First, we define mitigation as:

Mitigation is a set of pre-disaster activities directed at addressing the source of hazard, thus aiming at decreasing the threat posed by a potential hazard.

At the same time, in our view, adaptation is directed at preparing the system to perform in a superior way in response to a negative impact. By adaptation in the context of disaster preparedness, we mean:

Adaptation is a set of pre-disaster adjustment activities directed at creating conditions within the human-induced system that enhance this system's resistance to an outside shock, as well as its response capacity to cushion a negative impact, thereby improving its resilience.

An example of mitigation would be activities directed a the reduction of CO_2 emissions, which are intended to decrease the effects of global warming; alternatively, practicing evacuation in case flood alarm is issued, building flood defenses, reallocation of economic activities to the areas less prone to hazards would belong to adaptive measures. A similar definition can be found in one of the project descriptions of Netherlands Organisation for Scientific Research (NWO, 2004). Interpreting adaptation in such a manner is similar to medical preventive measures taken in anticipation of an epidemic aimed at strengthening the individual immune system. In this manner, we argue, resilience is closely connected to adaptation, which can also be found in the

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[14] While we would say 'inherent and adjusting responses'; see our definition of adaptability below.

socio-ecological literature reviewed at the beginning of this Chapter. Mileti (1999, p.5) supports this view, regarding resilient systems as those that "can withstand en extreme event with a tolerable level of losses" and "take mitigation actions consistent with the achieving that level of protection". Note that Mileti uses 'mitigation', which we would substitute with 'mitigation and adaptation' as discussed.

A number of authors have introduced concepts that have a wide reach in disaster analysis. For example, Benson and Twigg (2004, p.21), in the context of research dedicated to increasing the safety of vulnerable communities and to reducing the impacts of disasters in developing countries, define *mitigation* as an all-inclusive concept, being "any action taken before, during or after a disaster to minimize its impact, including structural (physical) and non-structural measures", including post-disaster activities. The Board on Natural Disasters (1999, p.944), the US, shares this view on mitigation. At the same time, this concept seems to overlap with the term preparedness, which refers to the period in time shortly before a disaster and marks (*ibid*) "any specific measure taken before disaster strikes, usually to forecast or warn against it, take precautions when one threatens and arrange for the appropriate response". Preparedness, thus, can be considered, in our lexicon, as part of adaptation. Freeman, for example, uses preparedness in the meaning of contingency planning (see Freeman, 2006). Parker, Green and Thompson (1987), however, consider *adaptation* as an all-inclusive concept. German scientists (see for example, Messner and Meyer, 2006), in their turn, consider *vulnerability* a broad concept, including exposure indicators, elements at risk and susceptibility. The authors diverge in defining all these concepts, as discussed above. Resilience is viewed in a narrow sense, which makes in their analysis a part of susceptibility of ecological units. Susceptibility within the context of flood damage research, according to them (*ibid*, p.5), "in a broader meaning relates to system characteristics and include social context of flood damage formation, especially awareness and preparedness of affected people regarding risk they live with (before the flood), their capability to cope with the hazard (during the flood), and to withstand its consequences and to recuperate (after the flood event)."

To avoid confusion, however, we abide by making a distinction between pre-disaster measures as mitigation (directed at the reduction and control of hazard) and adaptation (directed at the improvement of characteristics of a human-induced system to respond to an adversity); and post-disaster resilience reflected in response and recovery activities. The definitions of concepts related to resilience in disaster analysis are discussed in the following Sections.

2.3.3. Our Definition of Resilience

At this point, it is clear that interpretation of resilience among economists often limits the application of the concept to the post-disaster situation alone. However, it is difficult to imagine that the inherent capacity of a system to respond to an outside shock should be seen as such an ultimately rigid category. Instead, similarly to immunity, it can be built up in advance to prepare the system for the outside threat. So, we state:

Resilience is the ability of a human-induced system to: 1. cushion a shock, responding to it by adjustment; 2. safeguard continuity, maintaining its main characteristics; 3. exhibit learning capacity to improve its protective mechanisms in the face of future perturbations.

This implies that, in our view, adaptation is naturally following the concept of resilience. Essentially, the two are closely connected; when the resilience stage in the immediate disaster aftermath, with its emergency recovery and restoration activities, is over, and some daily routine has returned, adaptation takes over to prepare the system for future threats. Kendra and Wachtendorf (2003, p.41), as a part of disaster analysis community, state that "resilience […] suggests an ability to sustain a shock without completely deteriorating; that is, most conceptions of resilience involve some idea of adapting to and 'bouncing back' from a disruption." Supporting this view, we note, furthermore, that adaptation can come from the stimulus within the system, but it can also be triggered from outside, like public policy. Therefore, within the scope of this thesis we shall consider the concept of resilience together with the adaptive capacity of the system, as 'resilience' emerges from continuous adaptation process, as well as adaptation is often enforced by the experience of a calamity. In Day (1987, p.252)[15], we find supporting evidence: "The economy may then be thought of as being made up of a set of interacting adaptive processes, i.e., as a complex, adapting system." This means that adaptability is inherent to the economic system, and thus naturally presupposes adjustments in the face of expected adverse events.

We can summarise here that the concept of resilience is an important element in disaster analysis, which describes the processes of adjustments and survival in an economic system under attack. Essentially, because under 'normal circumstances' an economy can be described by the notions of stability and robustness, resilience is unnecessary in the standard impulse analysis. Yet, in the studies of major disturbances, resilience provides content to the time dimension of the disaster concept: including adaptability element, it points to the need for preparedness in the *ex ante* situation, and can be seen as a key indicator for policy goal when considered together with sustainability. The latter is because enhancing resilience should be considered a policy-oriented cost-effective tool to manage catastrophic risk (Parker, Green and Thompson, 1987; Rose, 2006). Also, reflecting the ability of a system to cushion a major shock, the notion of resilience suggests that a certain time span after a calamity has to be taken on board of disaster analysis, lying at the core of establishing disaster consequences (with which we continue in the next Chapter).

The link between the application of resilience and policy action can be explored in the example of flood defence policy in the Netherlands. Eventually, one can note the straightforward connection between the use of the concept of resilience in damage assessment as a post-disaster policy instrument and its application for the purposes of building up the pre-disaster protection policies. Investing in improving the inherent resiliency of the whole economic system in advance can stimulate a better response to potential disaster, meaning lower losses, as well as a healthier reaction of the entire

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[15] We should add that Day's evolutionary approach to economic change offers perspectives that may be worthwhile to consider in the perspective of the risk society (see also Day, 1993, 2004).

economy to any adverse outside impulse. We shall discuss this issue in more detail in Chapter 8.

2.3.4. Concepts Related to Resilience

When discussing resilience, a number of other concepts come to the surface. In the previous Section we elaborated on resilience, mitigation and adaptation. However, some other terms need to be touched on briefly to avoid unnecessary confusion. In doing this, we do not pretend to establish unanimously accepted definitions, but rather to clarify the meaning of those concepts, with the aim of having some sort of 'operational definition' used in terms of this thesis.

As mentioned, Parker, Green and Thompson (1987) refers to susceptibility, vulnerability and resilience. Susceptibility seems to be a good place to start. According to the authors, *susceptibility* refers to the physical exposition to hazard, location of an object in the vicinity of potentially dangerous area. The EU project FLOODsite[16] defines it as the propensity of a particular receptor to experience harm (Gouldby and Samuels, 2005, p.26). For example, the location of a production site in the flood plane of a river makes it highly susceptible to a flood. *Vulnerability*, in our view, is static, and reflects sensitivity of the system to a disturbance, its potential to be harmed. In other words, vulnerability is the propensity of a system to incur damage. Therefore, clearly, a system can be susceptible to hazard, but not necessarily vulnerable. Next, *resilience*, as established in the previous Section, is a dynamic concept resembling the coping capacity of a system to deal with a shock (as well as the learning abilities to adapt in advance to potential dangers). As seen, Parker, Green and Thompson (1987) define resilience as a reciprocal of vulnerability; this, in our view, is not exactly the case. Also Adger (2000, p.348), from the environmental economist's point of view, states that the former is only a 'loose antonym' of the latter. Provided the dynamic connotation assigned to the definition of resilience, we can say that a system can be vulnerable to a shock, but this does not necessarily imply that it is not resilient anymore. Though vulnerable to a disturbance, the system may react to this in a resilient way, adjusting in the face of a calamity and neutralising its negative impacts.

The concept of resistance comes close to resilience. *Resistance* is the ability of the system to bear a shock and withhold damage; resilience is the ability to react. The subtle difference with resilience can be explained when thinking of resistance as a static concept. Then, it can be noted that resistance is the reciprocal of vulnerability, which expresses the exposure of the system to a shock and its potential to incur damage, and which can be seen analogous to Rose's concept of static resilience (see Rose, 2006; his concept of dynamic resilience would be analogous to our concept of resilience). However, whereas a system has a given (or developed) level of resilience, its resistance can be different depending on the outside shock (as much as the system is vulnerable to a different extent depending on the impact, see also Green, 2004).[17]

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[16] FLOODsite project for integrated flood risk analysis and management methodologies covers the physical, environmental, ecological and socio-economic aspects of floods from rivers, estuaries and the sea. For more information, consult also the website www.floodsite.net.

[17] Following Green (2004, p.323) "vulnerability can be defined as the relationship between a purposive system and its environment, where that environment varies over time", which directly points at the variability of vulnerability depending on the outside conditions.

Robustness is also sometimes discussed in the debate on resilience. A robust system is the one that is "healthy, strong, durable". With respect to disaster events, Rose (2006) defines it as avoidance of direct and indirect losses. The definition of robustness by Bruneau *et al.* (2003) coincides with our definition of resistance. Green (2003) suggests that a robust response, as opposed to a resilient one, is not flexible but rather makes system remain unaffected by shock. We may observe, thus, that robustness is often seen to be very close to resistance; yet the latter being applied from natural and social sciences; the former stemming from the economists' vocabulary. However, we shall notice that it is important to note that, in fact, the concept of robustness is conventionally used in marginal analysis of incremental change analysis in economics. Alternatively, a system facing a major calamity, as discussed in this thesis, cannot reveal robustness anymore, as it is severely damaged and is forced out of its equilibrium. Resistance and its reciprocal, vulnerability, in this respect seem to capture a broader connotation, also applicable to the analysis of events on a grand scale, which are in the focus of our enquiry.

Redundancy, as the measure of excess capacity (also found in Rose, 2006; and Bruneau *et al.*, 2003; together with the concept of resourcefulness[18]), can be seen as part of resilience, particularly in the sense of "duplication for preventing failure of an entire system" (Wikipedia). This interpretation of redundancy in the *ex-ante* situation fits the proactive character of resilience as we describe it – being a process and revealing adaptive features.

Finally, *sustainability,* which we already mentioned in the context of the ongoing discussion in this Chapter, is the ability of the system to maintain into perpetuity. The Brundtland Report (UN, 1987) defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (also found in the documentation on the EU FLOODsite project, Gouldby and Samuels (2005, p.26). As mentioned before, this is the reflection of the desirable state of the system in the view of long-term development and in conjunction with a wider spectrum of variables, describing the environment in which the system is operating. This positive character of the term distinguishes it from resilience, which has no value judgement. So, the system can appear resilient in response to a calamity, although this does not make it necessarily return to the desired sustainable path. Legitimately, Tobin (1999) considers "sustainable and resilient communities" within the context of hazard mitigation.

We can conclude at this stage that the underlying differences we noted between the concept of resilience and the related terms are often very delicate. Disaster scientists and those working in the related field of analysis should be more aware of this. To avoid confusion, within the framework of this thesis we shall stick to the definitions as outlined above.

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[18] Also, Bruneau *et al.* (2003), alongside robustness, redundancy and resourcefulness, include *rapidity* as a constituent of resilience. Yet, in our view, the definition of rapidity as the capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption, overlaps with our definition of adaptability in terms of avoiding future losses; and also has some positive judgment of achieving a prescribed goal, which we would rather assign to sustainability.

2.3.5. Core Concepts Shaping Disaster Analysis

The new concepts for disaster studies as we have defined them in this Chapter are not only necessary for describing the specificity of calamity situations, but also for gaining more insight into the processes behind economic disaster phenomena. For example, these new concepts may be used as tools to organise our thinking about precautionary policies preparing for a potential hazard, as well as thinking about action in the immediate disaster aftermath. Without identifying those elements involved in working of an economic system under extreme conditions, which we can understand and structure by introducing and clearly defining the essential concepts in the new field of disaster analysis, modelling cannot be realised. Now we can take a step further and look at how far the identified concepts can be useful in understanding and modelling disaster impacts.

We can imagine that when a country, hosting important production facilities, is hit by a major hazard, a part of the established economic network is gone, the system misses its constituent parts and thus cannot keep on working properly. The asymmetry of shock would then mean for a number of producers surrounding the economy that they lose their customers; others lose suppliers. Those producers experiencing difficulties will not be able to perform their obligations to third parties, causing an avalanche effect throughout the economy. Imbalances in relative proportions between the various sectors within the economy then become commonplace, leading to excess supplies and demands on various markets, neither of which is desirable. Ultimately, this would translate into shortages for consumers, who will not be able to obtain all the necessary goods to satisfy their needs. The described processes in the immediate disaster aftermath are a reflection of economy’s vulnerability, the degree to which it incurs losses as a result of a hazard.

Practice has shown that negative consequences experienced throughout the economic network cannot be automatically restored (in particular on regulated markets) because of disproportionalities and rigidities that impede the return to balance (see Chapter 3 for further discussion on rigidities), emerging on a large scale. The system appears to be severely out of equilibrium, and needs to reorganise itself to return to a balance. This means that a whole range of adjustments, stemming from the resilience potential of an economy, is required; but how to think about that? On the one hand, the comeback to a (new) equilibrium can be entirely entrusted to the market forces. On the other hand, is the market capable of providing a solution to such a complicated problem? We should clarify: is the outcome of the market solution desirable, efficient, fair? Is it impossible that market failures and rigidities sabotage the whole recovery process? Probably, in some cases another party – the regulating hand of the government – is necessary to restore the balance at the lowest cost. At least in regulated economies, for example, the Netherlands, the mix of market self-forces and government intervention seems inevitable. However, as soon as the government steps into the matter, it should have some guidelines which options are available and which policies are best to help gain control of the situation. Economic modelling of potential disruption and the options open for recovery should guide the decision-making process in the important post-disaster phase of development.

Also, a proactive approach to disaster preparedness can be analysed from the point of view of risk-averse policymakers, where the precautionary principle can play a role (see COMEST, 2005). This principle first emerged in the context of ecological debates, and is also applied in the studies of risk society[19] (see Giddens, 1999, as well as Beck, 1992). According to the precautionary principle, an activity should not be undertaken if one can expect that it will bring substantial or irreversible negative effects. Applying the precautionary principle to disaster preparedness, this can be interpreted in terms of activities that *should be undertaken* if it is to be expected that idleness ('doing nothing' and hoping that a disaster does not happen) can bring about substantial or irreversible negative effects. Indeed, the possible irreversibility of the effects of a disaster (where system and/or group risks may play a significant role) should be considered seriously and brought to the awareness of both the broad public and the decision-makers. In essence, the analysis of the robustness and resilience of an economic system, and its adaptability to a changing physical environment can help identify those elements of an economic network, which can endanger the stability of the entire system if they are displaced. This can involve both the elements of physical infrastructure, and essential nodes in the socio-economic network.

The forms that adaptability and resilience can then take in the framework of policy-making can be an interesting research topic. With the background definition established, one can investigate what those terms mean in reality, and which measurements should be used (see Rose, Oladosu and Liao, 2007). For example, according to some sources (e.g., NWO, 2004), adaptation can be regarded as autonomous (i.e., as we have suggested above, led by market forces), or it can be driven by public policy in the anticipation of a threat. The latter can be seen, in turn, as the planning of adaptations as a reactive process, like steering the recovery in the aftermath of a calamity; or as an anticipatory action, building up response capacity in advance (a clear revelation of resilience potential). It can be expected, according to the source (*ibid*), that in the long run adaptability may take on extreme forms, such as changing spatial patterns of residence, work, agriculture, infrastructure and nature.

We can distinguish here a range of scientific efforts to make adaptability more tangible. Essentially, these are aimed at defining critical system characteristics, which should be able to guarantee the continuity of operation in the face of calamity. Kendra and Wachtendorf (2003, p.44) state that researchers for the New York State Department of Conservation and Recreation (DCR) and the Multidisciplinary Centre for Earthquake Engineering Research (MCEER) in the US identified the dimensions along which resilience can be measured. They claim that these contain robustness, resourcefulness, redundancy and rapidity (similarly to Bruneau *et al.* 2003). Kendra and Wachtendorf add (2003, p.45): "resilience should be seen not merely as the application of scientific knowledge and techniques, but also as an art." This argument stems from the finding that all disasters are 'same, yet different' (supported by Denhardt, 2005), which presumes that we have to be prepared for their consequences in advance, yet be able to

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[19] Following Giddens (1999, p.3), "A risk society is a society where we increasingly live on a high technological frontier which absolutely no one completely understands and which generates a diversity of possible futures". Further, Giddens remarks (*ibid*, p.4): "A world which lives after nature and after the end of tradition is one marked by a transition from external to what I call *manufactured risk*. Manufactured risk is risk created by the very progression of human development, especially by the progression of science and technology." Because modern risk societies, to a certain extent, are disconnected from nature, the growing importance of man-made risks is stressed, while risks connected to natural hazards as a threat to modern societies are somewhat disregarded. We shall agree on the former point, yet would draw the attention of the reader to the danger of underestimating the importance of the latter point, which we shall follow with the discussion concerning vulnerability of modern industrialized societies to natural hazards in Chapter 3, Section 3.2.2. We shall also come back to the risk society in Chapter 9.

improvise on the spot in each particular calamity case. What the authors offer as a system to achieve resilience is that it should possess, firstly, a high degree of organisational craftsmanship; secondly, the ability to respond to the singularities; and thirdly, a sense for what is the same and what is different from prior experience in every new experience. This suggests that a resilient society or a system should have some sort of built-in philosophy about the manner in which it should respond to a shock when occurs in reality, as well as the capacity to adjust immediately when facing an unknown danger.

On the more operational, however still aggregate, level Tobin (1999, p.16) suggests that the following characteristics should apply to sustainable and resilient communities, which can be addressed in advance:

- Lowered levels of risk to all members through reduced exposure to the geophysical event.
- Reduced levels of vulnerability for all members of society.
- Planning for sustainability and resilience must be ongoing.
- High level of support from responsible agencies and political leaders.
- Incorporation of partnerships and cooperation at different governmental levels.
- Strengthened networks for independent and interdependent segments of society.
- Planning at the appropriate scale.

We may also draw from Pingali, Alinovi and Sutton (2005), who offer the following strategies to augment the food system's resilience, which can readily be applied to more general cases: strengthening diversity; rebuilding local institutions and traditional support networks; reinforcing local knowledge; and building on economic agents' ability to adapt and reorganise.

Other examples are the works of Cole (2004a,b), where, in a series of studies on the economic effects of hurricanes on the Caribbean island of Aruba, he distinguished several 'survival strategies' for a small island economy (however, without mentioning the concepts of resilience or adaptation explicitly). This would typically include a duplication of crucial lifeline systems such as the food and drink systems, particularly around international hotels (where reliance on tourism sector is critical for this island economy). In case a disaster hits the primary lifeline supply system (i.e., water, electricity and gas supply, transport and communication systems), excess capacity should be available to ensure the continuity of the usual activities. This, however, comes at a price of *a priori* investments, which cannot be spent on alternative purposes, be it consumption or investments in capital. All benefits and costs of such precautionary measures should be considered and carefully weighed when a particular decision has to be taken.

What we are especially interested in, within the context of our research, is the application of the principles outlined above to differentiation between ways the economy can react in response to a disturbance, neutralising the negative consequences in production interruptions. Built on the reviewed methods and strategies to make resilience and adaptation operational, we suggest that the following schedule can be applied:

1. ensure business operation continuity outside the impacted area (supply side) by means of:

    a. having a back-up lifeline system, including electricity, water and gas supplies, telecommunications, alternative transportation routes, *et cetera*;
    b. maintaining extra stock (both for raw materials and final products);
    c. ability to switch in a flexible way to new procurement and consumption markets;
2. ensure the availability, distribution and exchange of information as a crucial asset in immediate decision-making for economic agents and government institutions;[20]
3. substitution of lost domestic output by increased production of goods and services by businesses at home, utilising spare production capacities – on the supply side;
4. adjustments in the consumption pattern via product substitutability on the demand side;
5. diversification of the economic system – both on the production and consumption markets to reduce dependency on the outside resources.

It can be noted that the classification that we offer is directed at the micro- and meso-levels of individual producers and sectors of an economy. At the same time, ensuring the building up of resilient individual elements of the whole system will expectedly have an aggregated effect on the economy level. Kendra and Wachtendorf (2003, p. 48) draw a connection between links at various levels. They assert that, on the one hand, resilient communities provide the context in which organisations themselves become more resilient. On the other hand, however, organisations provide the infrastructure for a community's resilience, in that organisational resources, networks and overall capacity are what make coordinated community-wide response possible. They conclude, "the relationship is iterative and telescoping, played out across multiple scales within organisations, between organisations and between organisations and the community."

The outlined classification of resilience embodiment in practical activities, as we propose, provides another possibility to demonstrate that adaptability and resilience are seamlessly connected. Some of the elements (also found in Rose, 2006, though structured into the inherent and adaptive resilience) evidently belong to the post-disaster performance, such as the ability to find new business partners, adjustments in consumption patterns and provision of information. The rest of the constituents depict adaptation variables, building up resilient capacity, which cannot emerge at the moment when a disaster hits, without being 'prepared' in advance. This includes back-up systems, additional stocks, economic diversification, and the existence of spare capacities for production, which will appear to be essential to our discussion of rigidities in the next Chapter. Unless present in advance, these options cannot be used as the calamity strikes. Therefore, the economic agents have to take *a priori* action to ensure the presence of resilient capacity. Yet, in the longer run, resilient response in the immediate disaster aftermath, also possessing a learning element, gradually becomes an adaptative process, shaping preparedness to the potential hazard in the future.

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[20] The utter importance of information as a decisive factor in immediate reaction and planning was substantially emphasized by the US Bipartisan Committee reporting on the consequences of hurricane Katrina (see US House of Representatives, 2006)

2.4. SUMMARY AND DISCUSSION

In this Chapter we addressed conceptual issues connected to the definitions of a number of important concepts in disaster analysis. Firstly, we focused the concepts of disaster and catastrophe, often alternated in use. We established that there is not much convention on the definition of the very subject of disaster studies, which essentially underlies the lack of order in the field, let alone the existence of the field itself. However, we attempted to bring more clarity and define a disaster, resulting from the interaction between natural and human-induced systems, as a shock going beyond the scale of what can be referred to as a minor or marginal impact, affecting the established balance throughout the economic system with explicit spatial and temporal dimensions. Catastrophe, in turn, is a ’severe disaster’, causing acute displacements of a system, in its extreme leading to overall failure. In fact, drawing a line between the two sorts of calamities is not easy, but we state that is it a matter of scale and severity, which distinguishes the two.

In the debate about long-term effects of flooding and society’s capability to recover, a number of concepts are gaining increasing attention in disaster analysis, among others, *resilience* and *adaptation.* A problem is that neither the multidisciplinary literature covering disaster modelling, nor the economic literature, have developed generally accepted definitions. Yet, some trends can be observed. They certainly deserve more elaboration.

Taking into account a wider temporal span in disaster analysis, *resilience* becomes an essential matter as it has direct implications on the total damage sustained. We need this concept in the study of major calamities, which imply severe disturbances, as a twin brother of robustness that is used in the minor shock analyses. Resilience, in our view, reflects a system’s capacity to adjust in the face of tribulation and respond to it in a way, which could cushion the immediate negative impact, maintaining its main characteristics (Gunderson and Holling, 2001; Allenby and Fink, 2005). Some authors, especially from the (socio-) ecological field, attribute learning and adaptive capacity to resilience as well (see, for example, Kendra and Wachtendorf, 2003; Resilience Alliance, 2005), with which we agree, too. In connection to this, it is assumed that a higher resilience level can make an economy recover faster and at lower cost (Rose, 2004a). Recently, in disaster consequence studies, resilience plays a more prominent role: re-organizing the system so that it responds rapidly in a flexible way to a shock, becoming a goal in itself. In her study on water management system, De Bruijn (2004) points to the superiority of resilience strategies. Besides, a prudent policy-maker would couple this goal with the sustainability principle, providing resilience with normative contents (Tobin, 1999).

To enhance resilience of a system, one has to think in terms of disaster preparedness. As immunity, resilience can be improved in advance. In this sense, it is connected to the concept of adaptability. *Adaptation*, thus, is directed at the preparation of the system to the expected adversity, and can cover local, national and even global aspects. Adaptation is intended to reduce inherent vulnerability of a system to a calamity, as well as to improve its response capacity, i.e. resilience. The difference with the widely used *mitigation* strategies is that, contrary to adaptation (which is aimed at the system under attack), mitigation is seen as the entirety of strategies, aimed at preventing or limiting the adversity.

The debate on the concepts in disaster analysis, described in this Chapter, is completely open and asks for ongoing contributions. We hope to have provided a consistent examination on a number of issues from the economic point of view. Because we have started from the fundamental questions guiding disaster analysis, it was necessary to provide the definitions of core concepts offering a basic structure for an integrated thinking about the processes in complex economic systems provoked by an event of a major disaster. In the following two Chapters of Part II, we shall continue with discussing economic concepts in, approaches and frameworks for modelling disaster consequences.

Chapter 3

Consequences of Disasters

3.1. INTRODUCTION

We would like to recall two aspects of disasters that we established in the previous Chapter: the term ’disaster‘ does not refer to the hazardous event itself, but rather to its consequences, and is defined as the interaction between natural or manmade hazards and human-induced systems. Shinozuka, Rose and Eguchi (1998, p.1) make a compelling observation:

> “…earthquakes are much like the old philosophical conundrum: if a tree falls in the forest and there’s no one around, is there a noise? Similarly, in an area with a small population and little economic activity, an earthquake is not very meaningful.”

This brings us to the point that when talking about catastrophes, we are clearly dealing with situations where human settlements, activities and lives are destroyed, whereas otherwise it is just a rage of nature. A wide range of effects can occur, such as loss of life; psychological trauma’s; devastation of property and assets, both residential and business-related causing deterioration of welfare; curtailment of human activities caused by failure of public services; interruption of business and production activities; damage to historical and cultural heritage; decay to pastures and arable land; destruction of environmental conditions, ecological imbalances, and so forth. The multidimensional character of consequences results in the analysis of disaster impacts involving a variety of disciplines, including, among others, economics, sociology, ecology, engineering and environmental sciences. As pointed out in this thesis we limit the scope of exploration of disaster consequences to the study of economic effects of a major adverse shock (we tackled the issue of scale in Chapter 2, Section 2.2.2).

Besides, it is important to realise that, as a disaster is compounded of all the impacts it brings with it, it should therefore be considered improper to regard one effect as superior to the other[21]. What we are attempting to achieve is, concentrating on the economic side of calamity consequences, to contribute to the understanding of the

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[21] For example, we shall not evaluate the non-monetary impacts on households, which is becoming traditional in flooding literature. We refer to MAFF (1999), Alterra (2003), and Van Ast, Bouma and Francois (2004).

nature of devastations and the means to deal with them, preparing contemporary society for potential disturbances. This makes us realize that the stakes are high. In this Chapter, we shall closely study the effects disasters may have in modern societies. We shall try to distinguish between various types of impacts, and prepare the stage for economic impact modelling, which will follow in Chapters 5 and 6.

3.2. CONSEQUENCES OF DISASTERS

A first task is to distinguish essential aspects of disaster consequences. First, we want to pay more attention to the *scale* of the event that is studied. In the previous Chapter, we have found that it is the scale of the distress in particular, which makes a disaster a specific topic for research. On the one hand, studies of disasters are different from the conventional studies of marginal or step-wise changes, like incremental change in tax policy, trade tariffs or government expenditures. Impacts brought by a calamity are conceptually different, due to the very scale of the event. This stems in particular from the observation that a sum of a number of marginal changes would not produce the same outcome as one major shock (Van der Veen, Vetere Arellano and Nordvik, 2003). This means that we have to open a new chapter in the studies of impact analysis, with special attention for disasters. Needless to say that catastrophes, as extremely severe disasters, should occupy a separate niche exploring system failures.

There are a number of aspects that are essential in determining the magnitude of a calamity. First of all, on the global scale, climate change is often recognised as a factor contributing on the one hand to the increasing climatic variability and changing exposure to hazards; and on the other hand to uncertainty regarding its effects in specific localities. Next, there exists a differentiation of disaster effects in the literature between developed and developing countries, as the character of damages sustained depends on the economic (infra-)structure of the society. In the following subsection, we shall cover these topics and concentrate on the discussion of disaster consequences in developed countries, present rigidities and challenges during response and recovery stage. Because many issues in disaster and extreme event analysis are considered to be connected to the ongoing climate change processes, we shall first start with that.

3.2.1. Climate Change: a New Challenge

Disasters are particularly dangerous because they are difficult to predict. Currently, a number of challenges can be identified that may be expected to contribute to the (more frequent) emergence of calamities (MunichRe, 2006). The scale of a disaster depends, first of all, on the nature of the hazard and secondly on consequences resulting from this. However, the two are connected: the stronger the natural downturn, the more severe the consequences. If the hazard becomes increasingly likely, and the consequences of this are not known precisely, but are expected to be momentous, the situation deserves special treatment. One of the broadly recognised dangers at the moment is climate change, posing additional pressure on the development of the entire globe. We shall examine what this could mean for industrialised societies in particular.

The last decades have shown growing awareness on the increasing concentrations of ‘greenhouse’ gases in the atmosphere, which are believed to cause climate change.

This is currently identified as global average warming (as pointed out by some experts, see the report of the International Panel for Climate Change, IPCC, 2001, p.72), and is identified by the increase in the number and severity of extreme weather events, increased precipitation and the sea level rise (Van Aalst, 2006). Following US National Research Council (2002, p.1) “Abrupt climate changes were especially common when the climate system was being forced to change most rapidly. Thus, greenhouse warming and other human alterations of the earth system may increase the possibility of large, abrupt, and unwelcome regional or global climatic events.” This means that nowadays, when global environment is changing rapidly, it may be the reason why the world more frequently experiences extreme disasters, such as tsunamis, earthquakes, floods and hurricanes. As apparent from different sources (IPCC, 2001; World Wildlife Foundation, WWF, 2004; US National Academy of Sciences, 2005, *et cetera*) this trend is increasing. The consequences of this are virtually unpredictable. Although we can assume that man can hardly influence the probability of a hazard, it is becoming widely acknowledged that unscheduled extreme natural events will form part of our future. For example, following Penning–Rowsell and Peerbolte (1994, p.9), and indirectly also Van Aalst (2006, p.12), the potential for large-scale flooding exists all over Europe (see also other recent publications supporting these developments, like Van Dorland and Jansen, 2006; Stern 2006 and IPCC, 2007). Therefore, we have to take the unexpected into account when thinking about development trajectories (the argument is also supported by Benson and Twigg, 2004, and Hungarian Academy of Sciences, 2004). Identifying climate change and its effects as potential part of catastrophe emergence mechanism necessitates admitting that we are in fact forced to adapt to living in the world where disasters have high potential. Schipper and Pelling (2006, p.30) point out that “the scholarly realms of disaster risk and climate change are also starting to merge”.

In an attempt to gain some measure of control over the climate change developments and their consequences at large, Helmer and Hilhorst (2006, p.3) plead for what we would interpret as an *integrated* approach (we shall return to the discussion of this issue in Chapter 8, in the context of Dutch water and flood management), which could include

- better coordination among the climate change, disasters and development communities;
- an even-handed attention to the reduction of greenhouse gases and the risks associated with climate change, including through enhanced disaster management; and
- improved conceptual and methodological approaches to understand and respond to local manifestations of disasters while simultaneously addressing underlying complex and partially global processes.

This statement provides a wide platform for debate, which aims at bringing together climate change challenges, and couples them to disaster analysis and development trajectory planning. O’Brien *et al.* (2006, p.64), however, make a step further and connect the climate change problem with disaster management and resilience-building:

> “Disaster policy response to climate change is dependent on a number of factors, such as readiness to accept the reality of climate change, institutions and capacity, as well as willingness to embed climate change risk assessment and management in development strategies. These conditions do not yet exist universally. A focus that neglects to enhance capacity-building and resilience as a prerequisite for managing climate change risks will, in all likelihood, do little to reduce vulnerability to those risks”.

To achieve those goals, Van Aalst (2006, p.5) points out that challenges posed by climate change can not be managed separately from a broader context of development: "…the additional risks due to climate change should not be analysed or treated in isolation, but instead integrated into broader efforts to reduce the risk of natural disasters." Besides, Thomalla *et al.* (2006, p.47) suggest what they call the following experiments: 1. Enhancement of resilience/vulnerability dialogue; 2. Identifying regions of large-scale vulnerability; 3. Execution of vulnerability analysis using a formal methodology. We notice that both O'Brien *et al.* (2006) and Thomalla *et al.* (2006) point out the methodological underpinning behind disaster vulnerability analysis. To this end, the conclusion can be drawn that not only evaluations of disaster consequences themselves, but also a wider range of goals, such as studying resilience, contingency planning as well as designing development trajectories connected to climate change depend on the theoretical grounds of disaster analysis. Therefore, we shall continue elaborating how economic damage can be identified and modelled.

3.2.2. Disaster Impacts in Developed and Developing Countries

Another important consideration in studying disaster consequences in economic terms is that it matters which type of economy is affected (on hazard vulnerability of small cities versus big agglomerations, see Cross, 2001; and MunichRe, 2005). One example is the distinction between developing and developed economic systems. Some authors claim that disasters in developing countries result in much more severe devastation than in developed countries due to the vulnerability of the former triggered by a high degree of susceptibility[22] (see in particular Mechler, 2004; but also Christoplos, Mitchell and Liljelund, 2001; Murlidharan and Shah, 2003; Pingali, Alinovi and Sutton, 2005); at the same time, other authors consider the study of disruptions in industrialised countries as a priority because of increased complexity (like Morrow, 1999; Steenge and Bočkarjova, 2007). In this subsection, we shall address the differences stipulating the emergence of this division. In the Section 3.2.3 we shall deepen the discussion of disaster impacts in developed economies.

Let us look at the core of the differences. The reason why developing countries suffer severely from a disaster is that they are highly susceptible to natural hazards – with generally lower protection standards, stemming from the inability of these countries to finance advanced protection measures. Also, the high level of vulnerability of these economies to a calamity is often stipulated by increasing sensitivity to climatic variability due to dependency on agriculture and basic industry. These are also inadequately developed to satisfy the needs of growing population. Also, problems of conflicts, governance and weak public financial management further impede development (see Benson and Clay, 2003). The question whether such societies are becoming more or less resilient remains open. In these terms, high vulnerability of developing countries to natural hazards combined with low level of resilience, inability to cushion the adverse impact can turn a hazard into a devastating disaster.

Alternatively, we have to be particularly aware of the consequences of these natural tribulations on modern societies, as, traditionally, people found it attractive to establish their settlements in places such as river banks, river mouths, coastal areas, *et cetera*, because this was advantageous in terms of trade, as well as for recreational

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[22] See the discussion of these concepts in Chapter 2.

purposes. Settlements in these areas are naturally prone to forces of nature, and need additional protection. The reason that contemporary economies are significantly sensitive to potential calamity and why it is becoming increasingly challenging to cope with them lies in the increasing accumulation of economic assets and economic activity at a speed, which has never been witnessed before. UN/ISDR (2002) make the following general note: “Population density and growth, unplanned urbanisation, inappropriate land use, environmental mismanagement and loss of biodiversity, social injustice, poverty and short-term economic vision are important determinants of vulnerability.” The issue is also recognised by the EU Commission (2006), which, in drafting a directive on the assessment and management of floods, points to two trends in the development of flood risk, namely, increase in scale and frequency of floods, and marked increase in vulnerability. Developed countries are in general less susceptible, as they are able to invest continuously in advanced protective measures. However, the level of vulnerability of industrialised economies is not easy to determine, as at least two factors contribute to it. On the one hand, these systems do not rely on agriculture anymore, which implies higher resistance. On the other hand, a developed economy consists of a complex system of inter-industrial network. Rose and Guha (2004, p.120) note in this respect: “Greater interdependence causes these direct losses to ripple through the economy to a greater extent via many rounds of cost increases and lost purchases and sales. Greater self-sufficiency means an economy is more vulnerable to a disaster within its borders because of reduced trade with the outside world.” This suggests that the sensitivity (or, rather, vulnerability) of a modern economic network to outside shocks, however, remains difficult to establish, as interaction effects are involved throughout the entire system, and the loss of a part of this system should be considered in the context of the entire economy. Therefore, we propose that it is essential to study complex economic systems as they become affected by major adverse shocks.

Besides vulnerability, we also need to determine the level of resilience of modern systems to major outside shocks. During recovery, use of excess production capacities in the non-affected areas, resulting in production substitution; adjustments in economic behaviour of firms and households; as well as other ways of resilient response of an economic system to a shock can take place. The magnitude of these cushioning effects depends on the availability of alternative sources of supply and demand in the economy; the duration of the physical disruption; and the possibility to extend production. In general, assessing in advance whether alternative sources are available and whether production elsewhere can be relied upon, remains an extremely difficult task. However, this should be an essential part of disaster analysis. Also, although modern economies have undergone substantial change during the last century towards information societies based on knowledge (on information technology developments in connection to hazard perception see Mitchell, 1997), high-tech production and services, it is not apparent whether their ability to respond to an adverse impulse has deteriorated or improved. What can be stated with a high level of certainty is that modern economies have acquired new qualities, which need to be studied. Pelling (2003) asserts: “Urbanization affects disasters just as profoundly as disasters can affect urbanization”. At present, only a few studies exist which perform in-depth explorations of resilient response in industrialised economic networks. Nevertheless, more attention is now being paid to this topic, among which also our current study.

3.2.3. An Industrialised Economy as a Complex Circular Flow System

Further in this Section, we shall focus on the description of the impacts of a disaster in an economy with a highly developed industrial structure. Essentially, because of the complexity of modern economic systems, their elements are tightly interconnected through a diversified multi-level system of links. With this in mind, we shall focus on the analysis of linkages and dependencies within those systems. In this context, the concept of circular flow becomes a useful tool of analysis.

The circular flow as a framework in which we shall further discuss disasters can essentially be borrowed from macroeconomic theory (introduced by Quesnay, and later became a part of macroeconomic textbooks, see for example Mankiw, 1994; Chamberlin and Yueh, 2006). The concept of production as a circular flow dates back to early writers such as William Petty in England and Richard Cantillon in France. However, the Frenchman François Quesnay is generally credited with developing the first real model of the circulation of commodities between interconnected sectors of an economy. His Tableau économique, published in various versions between 1758 and 1766, is a representation of the production, expenditure and distribution of commodities in a two sector economy (agriculture and manufacturing). To express his views, Quesnay employed a very special device, the so-called zigzags. The first effort to transcribe the zigzags into a modern input-output format was made by Phillips (1955), after which many efforts followed (see Steenge, 2000). Leontief, in his early work on input-output tables for the USA, saw his (own) work as an effort to build a modern Tableau économique for the United States (Leontief, 1936,1941).

The idea of a circular flow is central to the understanding of how an economy works. An economic system can be thus viewed as a network where there are actions and interactions between households, firms, the government, financial institutions and the foreign sector. This has come to be known as the circular flow of income.

The basic scheme of flows in an economy can be observed between firms and households (found in Figure 3.1). We may notice that there are two loops: the blue arrows illustrate the flows of goods and services; maroon arrows stand for money circulation. This means, that between firms and households, there is a clock-wise exchange of labour as a factor of production to the firms, and of final goods from the firms to the households. Money streams go in the opposite direction to goods and services in the form of consumption expenditures of households for those goods and services, which are also revenues for the firms; and factor payments from the firms to households, which are essentially earned income for the supplied labour (i.e., wages). If we consider only the small inner circle of streams of money and goods between households and firms, we will observe that households are supplying labour and consuming final goods; and firms are producing goods in the economy. Also, a flow of intermediate goods can be observed from the market for goods and services to the market for factors of production. Intermediate goods are those goods that will be further used in the production of other final goods and services; these transactions can be traced, for example, within the input-output intermediate transactions matrix, to be discussed in more details in Chapter 5. It can also be visualised as a scheme of inter- and intra-industry flows as shown in Figure 3.2.

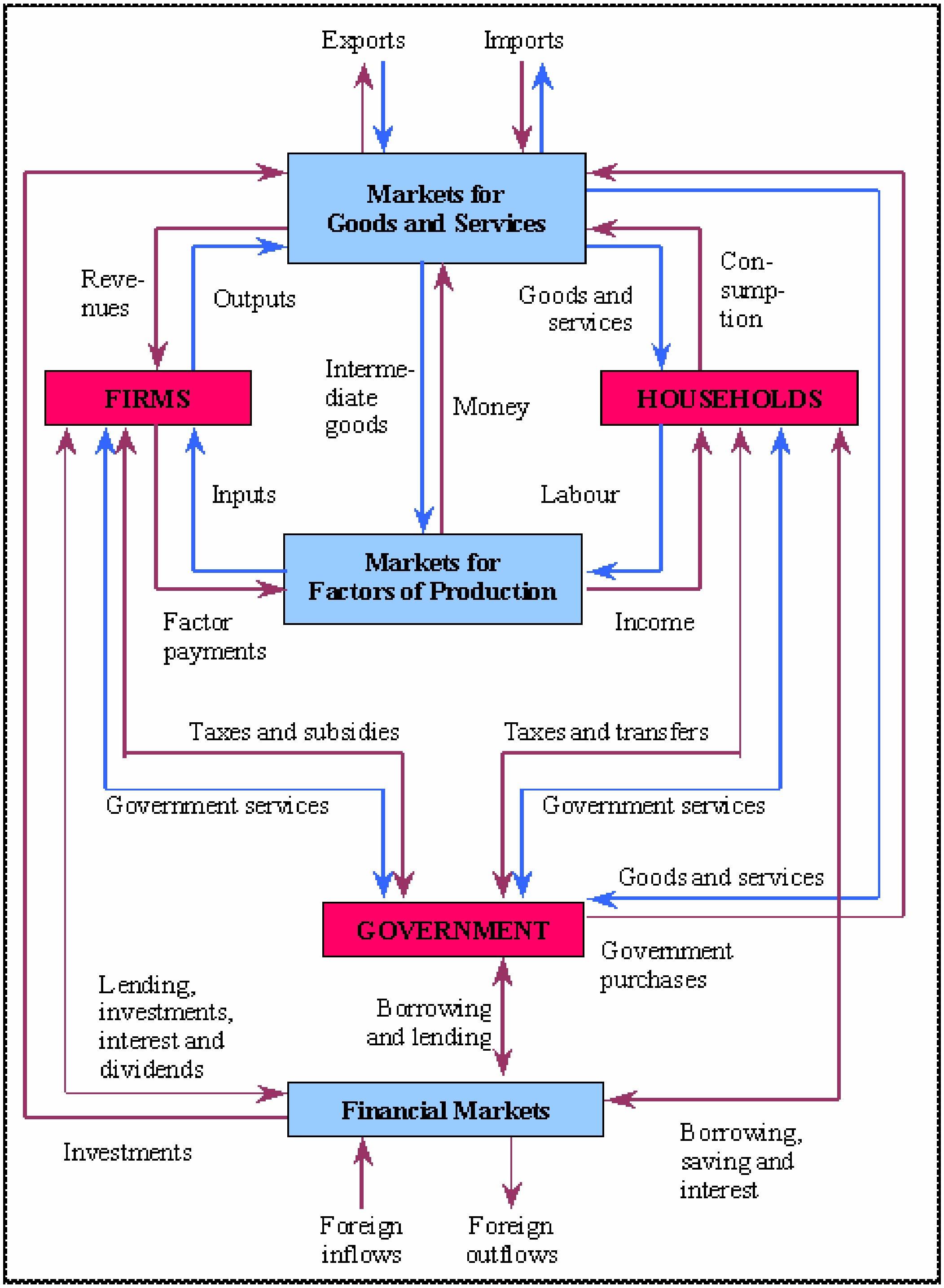

Figure 3.1. *The economy as a circular flow.*

If we extend our scheme and include government, financial markets and foreign countries, we shall obtain a more complicated chart of flows (Figure 3.1). Here, in addition to the above-mentioned streams of goods, services and money, we may observe also the transactions that are added due to the presence of the third actor, the government. Both firms and households have to pay taxes, in exchange for which they receive government services (that can be homeland security, defence, *et cetera*); and receive, respectively, subsidies and transfer payments. Government is also spending money (government purchases) for some goods and services on the market for goods and services; as well as borrowing and lending money in the financial market. Households and firms are participating in the financial market, too, by means of borrowing, lending, saving and investing, respectively receiving or paying dividends or interest.

The circle is completed by the leakages to and injections from foreign markets. Namely, some of goods and services that are produced in abundance are exported (for which payments are received); alternatively, those goods and services that are not produced domestically, or not in the required amounts, are imported (for which payments are made). Finally, financial markets in an open economy witness the inflows and outflows of foreign investments.

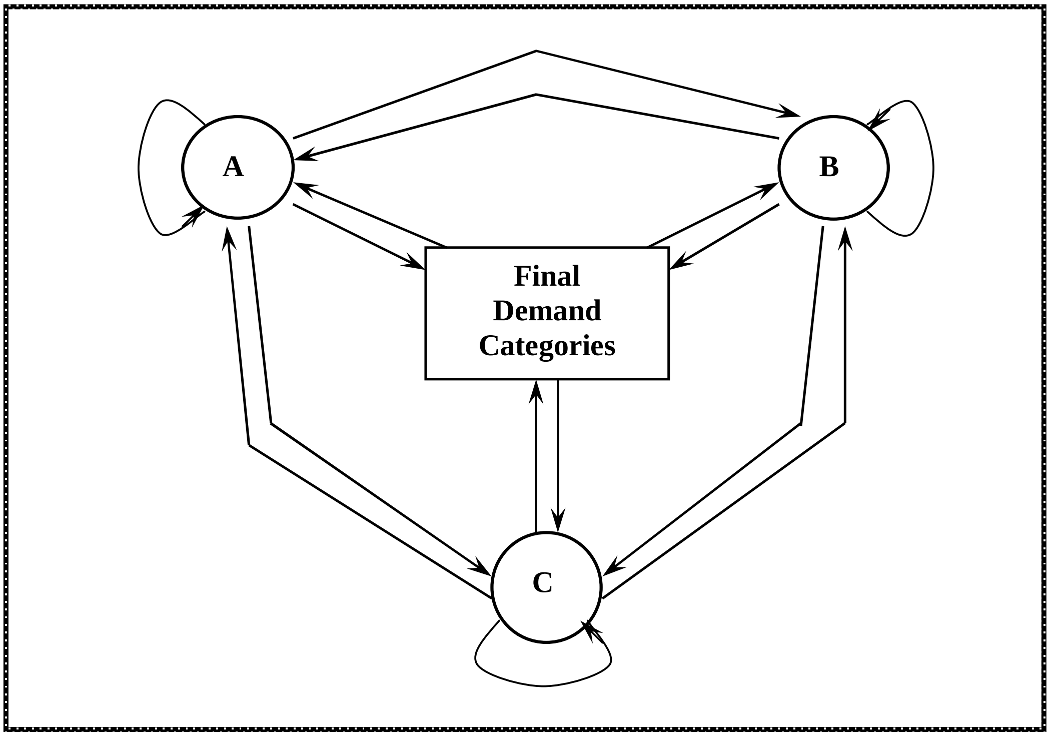

Figure 3.2. *Scheme of input-output inter- and intra-industry flows.*

Above, we referred to the circular flow as represented in terms of an input-output system. An input-output system provides a stylised representation of the complex circularity discussed above (see also Leontief, 1991; and Samuelson, 1991). In that system, each industry (denoted as A, B and C in Figure 3.2) is producing some amount of output. Part of this output will be used by the same sector (say, sector A) for its own needs. For example, part of equipment and machinery produced by heavy industry will be used in production (e.g., will go from A to A). Another part of sectoral outputs will be traded between other industries for their production needs. Thus, the flows of intermediate goods between all sectors can be observed (from A to B, from A to C, from B to C, and so on). It is also possible that intermediate goods stream in both ways between two sectors (like on the diagram above). This can be the case, for example, when agricultural sector is selling its outputs to the service sector, as well as buying some services from it for the purposes of production. The final part of output produced by each sector is allocated to the final demand categories, such as private or public consumption, investments or exports. Also, final demand categories are supplying labour and capital depreciation back to the productive sectors, which closes this input-output circle of flows.

It may be useful to introduce briefly the basic, static input-output model already at this place. (We shall come back to this model more extensively in Chapters 5 and 6). The model describes, in *a-priori* specified detail, the production of goods and services in an economy. The model is based on the notion of interlocking production processes. Two types of inputs into these processes are distinguished, i.e. commodities, the production of which is described in the required detail, and commodities, the production process of which is not described. Examples of the first type are the various kinds of agricultural products, the products of light and heavy industry and services. Examples of the second type are labour, imports, capital investments and government services in the form of taxes and subsidies. The latter category is known as the primary resources or factors. The production processes are modelled as so-called limitational production functions, also known as Leontief production functions. The term 'limitational' here means that the proportions in which the inputs have to be combined in production is fixed, basically on technological grounds. That is, the model (at least in its basic structure) does not allow substitution between inputs based on price movements, as in 'smooth' neo-classical production functions.[23] Standard, we have:

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{f} \tag{3.1}$$

where the (n x n) matrix **A** stands for the technologically determined matrix of input coefficients, **f** for the (n x 1) vector of exogenously determined final demand, and **x** for the vector (n x 1) of total output required to produce **f**, where we shall assume $\mathbf{f} > 0$. The dimension of matrix **A** informs us that the production of n goods and services is considered. The columns of the matrix stand for the inputs of the 'produced' or 'intermediate' inputs into each production function. (In Chapters 5 and 6 we shall discuss the way the input coefficients in **A** –and in the row-vector **l**, below- are obtained). For us, at the moment, it will be sufficient to notice that the coefficients a_{ij} of **A** represent standardised value flows from industry i to industry j. Matrix **A**, together with the information in **f** and **l** in [3.2] represent the circular flow in a very concise form.

To complete the model, we also need to introduce the 'non-produced' or primary factors or inputs. For the moment we shall only distinguish one such input, labour. We have:

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[23] The literature distinguishes several types of 'mixed' models, in which price effects do have an influence on input proportions. We shall only occasionally refer to those forms.

$$L = \mathbf{lx} \qquad [3.2]$$

where **l** represents the vector of labour input coefficients into each production function, and the scalar L total labour income or employment. The elements of **l** are known as the *direct* input coefficients.[24] Important is that the elements of **l** also are technologically determined. (One reason that the production of the primary factors is not considered is the fact that these processes are of a quite different nature, often involving long-term activities such as teaching and education in the case of labour. Sometimes also they are not sufficiently known as in the case of imports). Equilibrium prices **p** are given by the equation:

$$\mathbf{p} = \mathbf{pA} + w\mathbf{l} \qquad [3.3]$$

where w is the wage rate, such as euros per hour earned. (The row-vector $w\mathbf{l}$ also is known as the vector of value-added coefficients). We note that built-in is the property that labour can buy the economy's net output, the commodity bundle **f**. In fact, we have the following balance between income and expenditure, another instance of the model's built-in circularity:

$$w\mathbf{lx} = \mathbf{pf} \qquad [3.4]$$

The model enables us to calculate the effects of a change in final demand. Suppose exogenously determined final demand changes to $(\mathbf{f} + \Delta\mathbf{f})$. From [3.1] we then obtain straightforwardly:

$$(\mathbf{x} + \Delta\mathbf{x}) = \mathbf{A}(\mathbf{f} + \Delta\mathbf{f}), \qquad [3.5]$$

which gives us the new total output vector.

The above model essentially has only one scarce or limited factor, i.e. labour. That is, any limits to production are caused by a possible shortage of labour. (In models distinguishing additional primary factors, analogously, several of these production bottlenecks are distinguished). Suppose labour is only available in the amount $\underline{L}$. In that case, the economy faces a labour shortage if $\underline{L}<L$ as given by [3.2]. This means that the consumption bundle **f** is not feasible, and must be changed.[25] We should remark that the model does not address issues of unemployment, or, more general, of 'resources' that are oversupplied. So, if a situation where $\underline{L}>L$ is interpreted as a situation of unemployment, there are no mechanism that, e.g. would drive the economy towards a fuller use of labour as a productive factor. Such issues need to be addressed in more elaborate versions of the model.

The model usually is compounded on the basis of transaction reviewed for a specified period of time, which normally is one year. Finally, the model is static

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[24] The so-called indirect or total input coefficients are the elements of the multiplier or Leontief matrix of this model. This matrix also will be discussed in Chapter 6.

[25] More elaborate models put limits also on the availability of the produced goods, but for the moment we shall abstract from those possibilities.

because an analysis of the effects of investments is not part of the model. That is, investments are accounted for as one of the categories of final demand, but their effects on the economy's dynamics are not analyzed.

The equations [3.1],[3.2],[3.3],[3.4] represent the initial situation, i.e. before the shock. All entries are in money values. This is done because the empirical data needed to implement the model often are available only in money terms. Thus, we work with physical units expressed in monetary terms; see Miller and Blair (1985, Ch.2). An additional advantage is that money value representations enhance comparability between sectors, regions, and over time.

The static model, however, has a second form, the closed model. The standard form here is:

$$\mathbf{x} = \mathbf{M}\mathbf{x} \qquad [3.6]$$

The elements of the columns of **M** again are interpreted in terms of production functions. In this model, the distinction between 'produced' and 'non-produced' (i.e. primary) goods and services is not made; all commodities are equal in this sense. Total inputs are given by the vector **Mx**, total outputs by vector **x**. The model thus tells us that the solution, **x**, is the dominant right-hand eigenvector of matrix **M**. As we see, this matrix has dominant or Perron-Frobenius eigenvalue equal to unity, with **x** the corresponding eigenvector which gives the output proportions for this economy.[26]

The model [3.6] thus does not address questions involving the consequences of changes in final consumption demand. It only answers the question: which proportions are needed - in terms of inputs and outputs – so that the economy can reproduce itself in one period? This implies another difference with the open model [3.1] above. We may wish to interpret one of the columns of **M** in terms of the (proportions of a) consumption bundle for households. These households in turn provide the necessary labour inputs for the industrial processes. The coefficients in the row of **M**, which corresponds to the 'consumption inputs' column, then are comparable to the direct labour inputs in vector **l** of the open model. If the consumption vector is reasonably stable in proportions, this interpretation seems acceptable.[27] The price model corresponding to [3.6] is:

$$\mathbf{p} = \mathbf{p}\mathbf{M} \qquad [3.7]$$

That is, the equilibrium price vector **p** is the left-hand Perron-Frobenius eigenvector of **M**.

Suppose now that an economy is described by [3.6]. That is, we have a perfect fine-tuning in the sense that inputs and outputs are precisely matched. Suppose also that this includes labour and that this implies a situation of full employment. Suppose

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[26] In Chapter 6, we shall encounter a closed Leontief model where the coefficients matrix **M** is the sum of two input coefficient matrices, one standing for the technologies in use (**A**), and another for the real wage (**H**).

[27] Nonetheless, several authors object to this view because man would be introduced as a 'machine' requiring certain inputs to produce its product (i.e. labour force).

furthermore that for some reason the input vector changes to **My** where $\mathbf{y} \neq \xi \mathbf{x}$, $\xi > 0$. In that case, we have

$$\mathbf{z} = \mathbf{M}\mathbf{y} \qquad [3.8]$$

where **z** is not equal to **y** (because **y** is not an eigenvector of **M**). In that case, the perfect circular flow as depicted by equation [3.6] is lost. In fact, compared to the circular flow in [3.6], now (relative) over- and undersupply can be observed in [3.8]. If the situation persists for some time, entirely new efforts will be undertaken to restore some kind of equilibrium. The question then is if such a situation is advisable. The alternative is that the government prepares the country for the situation by *preparing* itself and by *preparing* various scenarios. That is the line we shall pursue later on, especially in Chapters 6 and 7.

3.2.4. Disaster Impacts in an Industrialised Economy; the Role of 'Rigidities'

The circular flow representation of an economy as above shows that all agents and all markets within a system are interconnected on several levels. Unexpected severe adverse shocks to an economic system cause interruptions in the circular flow and as a result, chain reaction eventuating in the paralysation of the entire economic network. One of the factors which can aggravate these effects are so-called rigidities, which can emerge due to what we would call technological factors (rather connected to the existence of the so-called 'critical' sectors that may cause the emergence of bottlenecks in production cycle); and institutional factors, (connected to contractual obligations, time lags or lack of information, *et cetera*). The latter fall outside the direct scope of this study, although they have an implicit influence on the former. At the same time, so-called technological factors guiding the emergence of rigidities are discussed further in this Chapter, as part of the exploration of production breaks and changes in economic structure, that at the core of our grand inquiry (as we shall see, the discussion of rigidities plays an important role building our model in Chapter 6). The other two issues that we are going to illuminate in this Section are the ability of an economic system to respond to a shock and the role of government as an important actor in steering disaster aftermath. In the modern economies, where private and public domains interact and form the economic landscape of the country, also the issue of responsibility, disaster prevention and preparedness come up to the surface. Specific to the thematic of disasters is the problem of insurance, which will also be covered below. First, we shall discuss rigidities.

'Rigidities'

For any economy, a set of rigidities can be determined which are inherent to a system. Delimiting the possibilities of the functioning system, these are important to consider in business-as-usual times; more than that, they become crucial in times of extreme situations as disasters. Here, we shall attempt to look at the processes behind a disaster in an industrialised economy, to identify those rigidities connected to technological factors, and their role shaping disaster aftermath.

Focusing on gaining a better insight into the nature of disasters and their economic consequences in contemporary industrialised economies, we in fact have to pay particular attention to the production and consumption activities, and disturbances thereof, the role of government and response of the private actors on its incentives. Essentially, an economy is a network consisting of multiple production establishments producing goods and services for different branches of industry and with different sizes and production capacities. When industrial units belonging to different industries within a locality suffer a different level of output failure, we talk about an asymmetric or heterogeneous shock. Heterogeneous character of damage induced by these shocks contributes to the specificity of disasters. Some experts (Cochrane, 1997a) note, in this respect, that should an economy experience a homogeneous shock, i.e., each sector would be damaged to the same extent, the total loss figures would be limited to 'direct damage' (often referred, but not limited) to physical damage; (we shall discuss concepts of damage in more detail later on in this Chapter, see Sections 3.3.4 to 3.3.6). This is because every sector within an economic network will shrink proportionally, and production activity can still go on, however, on a smaller scale. Yet, with a heterogeneous shock, so called 'indirect damages' appear (which are effectively connected to the disruptions in the economic circular flow; to be followed in discussions in the subsequent Sections 3.3.4 to 3.3.6), and may in fact even exceed the magnitude of the direct losses. Indirect losses thus seem more difficult to control, and following Cochrane (*ibid*), these are less sensitive to economic structure (be it industry *vs*. service dominated economy), than to damage pattern, size of the economy, preexisting conditions, and the manner in which recovery is financed. This means, that the relative magnitude of the economic system, system's vitality (which is directly connected to the concepts of adaptability and resilience discussed in Chapter 2), asymmetry of the shock, and recovery planning are central to the understanding of processes behind the disaster event in modern economies. In this Section, we shall concentrate on the latter two aspects.

As a result of the asymmetry in effects, one of the types of limitations experienced in an economic network is *production* bottlenecks. A 'production bottleneck' in an economy can be broadly defined as a situation in which overall production is jeopardised by one of the affected sectors, which can no longer supply the vital inputs to the rest of the economy. Several causal factors are at work here. One of them is a structural or technological factor, which is the existence of so-called 'critical industries' in an economy[28]. When, as a result of a natural disaster, an uneven loss of production throughout the sectors in the region is observed, these sectors become especially crucial. The size of such an industry is not significant; big or small, a critical sector is a highly important (perhaps, the only) source of input for other industries without close substitutes. If it becomes destroyed by a hazard, and no substitutes to it can easily be found (either in imports, inventories or excess capacity), many sectors depending on this critical sector will not be able to continue production, affecting other sectors in turn, thus jeopardizing the operation of the entire system. In such a situation, it is possible that total economic loss figures throughout the economy may substantially increase due to the indirect effects (see also Cochrane, 2004). Given these circumstances, disturbances in the critical sector will predominantly trigger over-proportional losses among the industries depending on the critical sector as purchasers, i.e., relying on it as the supplier.

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[28] Critical sectors, as we discuss them here, impose rigidities of different nature than those that are conventionally referred to as 'key sectors' in regional science and are often identified by means of significant backward and forward linkages obtained from the input-output analysis (for more background information on this issue, see, for example Hazari, 1970; Beyers, 1976).

A second type of rigidities, of an *institutional* nature, can worsen the picture. We shall mention some of them; these can be, for example, import limitations, payment lags, contractual obligations, lack of information, time necessary for finding new business partners or markets, as well as for re-contracting, *et cetera*. As the literature suggests (Cochrane, 1997b), the existence of such bottlenecks can substantially raise economic loss expectations. Furthermore, provided the existence of institutional rigidities, the technological factors become even more affected. As we mentioned in the paragraph above, critical sectors may get affected, limiting the capacity of the entire system to operate. With severe institutional limitations, in the immediate disaster aftermath each disturbed sector may in fact become critical, as in the initial time period resources are fixed, and cannot be substituted. This means that system is found out of balance and, what is more important, out of proportions. In such a situation, essentially, the sector suffering highest disturbance becomes the limiting factor, a ‘bottleneck’, for the entire economy until adjustments and/or substitution possibilities emerge. Also, it has been noticed that some certain proportions exist, in which households consume final products. In this sense, short-term resource rigidity (be it labour or raw materials) and stability of consumption bundle (the elements of the vector **f** in equation [3.1] above) fit in the input-output framework where technology is seen fixed. We shall return to the issues of rigidities and proportions in Chapters 4 and 6. Beyond that, there are some employment issues to be considered.

Another limiting factor in recovery efforts can be recognised, which are claims regarding ‘full employment’. In fact, we have to discuss it in terms of excess production capacities. For example, if in the rest of the country, where producers outside the devastated area are not fully employed, they can take over part of the lost output. However, if domestic substitution is not possible due to full employment of resources, the economy will hardly be able to adjust and expand its production activities elsewhere in the country, which can make the total loss figures for the entire country increase. Under the circumstances of full-employment and consequent limitations to growth, domestic producers (as well as consumers), if possible, may start looking for suppliers abroad, and, by importing the missing goods, ensure continuity of production. This, in effect, means that domestically produced goods are substituted for ones produced abroad. On the one hand, this helps companies outside the affected area maintain production in the short run. Yet, in the medium and long run, output that is imported, economically speaking, is considered lost. Effectively, the reason is that the goods produced domestically before the shock, and imported after a calamity, in the longer run become crowded out of the in-home market. With imports continually increasing, broader welfare effects can be expected in terms of employment, income distribution and price stability. We shall leave these issues for further elaboration outside the scope of this thesis; rather, we shall continue with other fundamental aspects governing recovery.

One of the broadly recognised critical sectors is lifelines, broadly defined as sector(s) providing infrastructure facilities (roads, railroads, and air transport), utilities (electricity, gas, water supply, sewage system) and communication services. If out of order, lifelines are a bottleneck for a whole area. Many authors emphasized their prominent role in contributing to losses (see, e.g. in Cole 1998, and Shinozuka, Rose and Eguchi, 1998). This is due to the fact that productive sectors are highly dependent on the supply of utility sectors, as well as infrastructure and communication in the contemporary world (see for example the studies of Rose and Benavides, 1998; Rose, 2004b). Many economic transactions depend directly on physical lifeline systems – for example, purchase of power and water by businesses and households, the trucking of goods between the industrial areas and to the final markets, the flow of information within and beyond the region. Dysfunctional lifelines may be responsible for paralysing the whole productive system. Even in cases when a disaster has a limited direct (physical) impact on the area, the indirect medium-term impacts due to physical infrastructure failures might be much more devastating, the effects of which may stretch far beyond the borders of regional or local economies.

The observation is important that (even) partial disruption of lifelines results in larger negative effects than can be seen, for example, directly from an input-output table. As indicated by Tierney and Nigg (1995), “data on the business impacts of the [Mississippi] 1993 floods indicate that lifeline service interruptions were widespread, were perceived by business owners as very disruptive, and were a much more significant source of business closure than actual physical flooding”. Other research outcomes support this finding. Based on the approach suggested by Chang (1998, p.82) and Rose and Benavides (1998, p.96) ‘lifeline disruption effect functions’ can be estimated for each branch of industry. Detected high sectoral dependence on lifeline supplies is central to the approach. From business survey, electricity dependence coefficients are deduced and employed to determine the deterioration of sectoral output as a result of physical lifeline disruptions. Alternatively, Okuyama, Hewings and Sonis (2002) offer to model lifeline collapses through the imposition of final demand impulse due to the interruption in lifeline services on the post-disaster input-output table with adjusted coefficients.

Modelling the effects of lifeline network failure on the rest of the country can be complicated further by their mutual interdependence. It should also be taken into consideration that lifeline networks make up a complex system, interconnected with each other. The Report of the Centre of Advanced Engineering (CAE), New Zealand (1997, p.12) states: “But, most importantly, in most cases there is a high level of interdependency between lifeline services. Each lifeline generally needs the others in some way”. Furthermore, Rose and Benavides (1998) note that modelling the cases involving *several* lifeline element disruptions is not a straightforward task. The reason for that is the presence of non-linearity of these interdependency effects. The CAE Report takes a step further, exploring lifeline interconnectedness. It distinguishes between the interdependence of lifeline networks in operation (if A fails, B fails), and in response (need to fix A to get to B). Essentially, lifelines deserve a separate study, tracing their effects on the performance of the rest of economic infrastructure, as well as their interdependences, which are crucial for economic disaster consequence analysis. In this thesis, our model will not include an explicit account of lifeline failure, although we acknowledge the importance of this factor for disaster analysis. We believe that this should be added as a specific dimension to the fully-fledged model, which we leave to further investigation. At the moment, we shall concentrate on the fundamental issues of interconnectedness. Further in this Chapter, we shall turn to the concept of damage and continue with the discussion of specific models in the next Chapter. Before that, we shall touch upon issues such as response and recovery and the role of governments in the modern economies.

To summarise, we should note that the various types and kinds of rigidities, as we have outlined them in this subsection, are connected to the concepts we have discussed in Chapter 2. In fact, we should see the emergence of rigidities and resilience as two sides of the same coin. If the economy is not prepared to a calamity, and has not built in advance some essential elements (consult in particular Section 2.3.5 of Chapter 2) improving its potential to bounce back in the face of a disaster, it will have to face extreme rigidities during the recovery period. This means, that to decrease the (potential) effects of those rigidities, the system has to direct its efforts on improving resilience before a disaster takes place. Yet, because, unfortunately, this is not always the path that is taken by the societies (the case of New Orleans provides a noteworthy example of that, as reported, among others, by Ink 2006; Menzel 2006; Kok *et al.*, 2006, and the Brookings Institute), we shall seriously consider the existence of rigidities in the aftermath of a catastrophe in the rest of the thesis. Clearly, government should play an important role in determining the milestones it aims at reaching. We shall continue with that.

The Role of Government

Government usually plays an important role in the immediate aftermath of a disaster. One of the typical observations one can make immediately after an outbreak of a calamity is that government is normally expected by the public to take the initiative and responsibility to provide basic human and financial resources to ensure the spin-off of recovery and disaster relief operations. The government can help improve the situation, providing both physical resources as well as incentives to the public and industry steering the revival of the economic activities. A number of possibilities exist, which have to be considered. On the one hand, this can include such activities as organised evacuation, provision of temporary dwellings, debris cleaning, *et cetera*. These rather belong to what we refer to as '*emergency aid*', and fall out of the scope of the current inquiry (to what we also pointed in Chapter 1). What we are more interested in, is the role of the government that offers *structural recovery aid*[29] in the form of extra financial resources to cover, for example, individual losses which were not insured, provide subsidies or tax relieves to the companies hit by a calamity, *et cetera*. However, it is a matter of knowledge, as well as political and economic intuition, to choose the right measure and instruments for recovery, providing the incentives, which should ultimately result in the desired effects. At the same time, lack of initiative and insight on the part of the government may lead to severe consequences, such as delayed response, unnecessary human and physical losses.[30]

From emergency experience in disaster situations it has become apparent that substantial inference into the essence of catastrophic events and their consequences is necessary before decisions are made. Probably one of the ways to model recovery is to employ scenario work, choosing various incentives that a government can implement, which should result in a variety of reactions of an economic system, leading to a spectrum of outcomes. We do not directly estimate the volumes of these investments to include them in the model, though indirectly we shall take this aspect of recovery into account.[31] It is an important aspect of disaster consequence modelling, as steering of an

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[29] This statement would require, strictly speaking, an assumption concerning the ability of the government to continue operation in the times of major adversity. To avoid complications at this stage of research, we shall stick to this very assumption.

[30] See the report of the US House of Representatives Select Bipartisan Committee investigating preparedness and response to Hurricane Katrina (The US House of Representatives 2006), emphasizing these aspects.

[31] As an apart, we should note here the relation of government expenditure to disaster loss and benefit accounting. It is important to bear in mind that some public expenditures connected to relief management are attributed to losses, while others to positive effects. Some of expenses are just transfers, such as taxes not received, due to a production standstill, unemployment benefits paid out, and the like. These transfers

economic recovery can have a substantial influence on the further development direction that the country takes, in turn determining the total loss figure. We recall that we interpret total disaster losses as a difference between the actual post-calamity path and the potential path that an economy would have followed without a disturbance.

Disaster Insurance

Also, often when discussing calamities in the junction of the private-public domain, the issue of *insurance* comes to the surface. Increasingly, this occupies more space in the debate among the issues on the public agenda, connected to the sharing of responsibility. A common argument is: if damage can be insured privately, those losses should no longer be a burden for the government. However, is it that easy? When addressing the issue of insurance, one should bear in mind that we are considering *large-scale* adversities, such as major flooding in the Netherlands (to which we shall return in Chapters 7 and 8), which are a special case in connection to insurance. Let us first explain the insurance principle. As a rule, insurance companies collect insurance premiums that (should) cover the payments of claims in a fixed period. Premiums are calculated on the basis of the average expected replacement value of the insured asset and the probability of the event against which the asset is insured. This means that incurred costs in a calamity are spread among the policyholders on a periodical basis, where premiums reflect average expected loss and include a mark-up. This principle is applicable to the cases where events have a certain predictable frequency. If this frequency (probability) is known, as well as the value of the insured assets, the insurance policy can be determined. However, once there is uncertainty with respect to the probability of an event (again, analogously to Knight), the average expected loss is more difficult to assess. Also, the difficulty to differentiate in time, space and among individual policy holders, makes insurance of ‘low probability-high consequence’ events more problematic.

Kunreuther and Michel-Kerjan (2005), in their study of terrorism insurance, point out several aspects, which make extreme events different from the usual insurance arrangement. Following them, we can apply three of these to disaster insurance, namely, catastrophic losses, interdependences and ambiguity. The latter means that a disaster event is typically characterized by a low, yet uncertain frequency, which complicates assessing and pricing the disaster risk for insurance companies (see also OECD, 2004). Catastrophic losses, basically, mean that large numbers of people as well as property can be affected, leading to substantial claims. Interdependence is stipulated by the chain of events where not necessarily the insured object or individual are liable for the occurring losses. This is in particular true for indirect losses (which we shall address later in this Chapter), when businesses or individuals suffer damage due to failures in other parts of the network, such as contemporary economies. Kunreuther and Michel-Kerjan (2005, p.48) summarise: “Failures of a weak link in an interdependent system can have devastating impacts on all parts of the system.”

As we see, a disaster is often an event bringing about high group risk and system risk. The former is a type of risk that not an individual, but a whole group of individuals incur damages; the latter concerns the critical shock which can result in failure of the

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reflect the redistribution of welfare, which, however, does not reflect the change in the total welfare of the society (see MAFF, 1999, p.25). At the same time, other expenditures, such as investments and increased public demand, should contribute to stimulating economic activity and can be seen as benefits.

whole system, be it economic, social, environmental or political.[32] This means that when a catastrophe takes place, a large group of individuals become affected at once, possibly covering a relatively large territory (to be referred to as affected area). Covering claims associated with such a disaster requires access to substantial amount of capital. This leaves basically two options: either insurance premiums for 'low frequency - high consequence' events may explode (making it virtually inaccessible for consumers), or insurance companies should have access to supplementary 'emergency' capital sources in case a major calamity happens. To this end, Jaffee and Russel (2006) point to the possibility of a government providing insurance companies with loans to guarantee smoothness of accounting and prevent bankruptcy within a specified risk-sharing arrangement. However, the authors also point out that even this may not be enough. Because the residual risk is high and hard to measure, re-insurers covering insurance company losses may be reluctant to provide this type of financial service, and the available ones may be expensive. Some authors (e.g., Cole, 1998) point to the disaster risk as uninsurable, a type of event that is sometimes described as an Act of God. Clearly, the above points to how future developments can evolve in rebalancing the public-private domain mixture in modern economies. In Chapter 8, we shall follow up on this topic.

3.3. THE CONCEPT OF DAMAGE

Among a variety of consequences a disaster may have, damage in general is a measurable category, a quantification of society's vulnerability. Economic damage in particular occupies a special place in disaster consequence assessments. The purpose of an a-priori assessment of economic damage is gaining insight in the damage potential that a hazard may bring. In this respect, the level of societal vulnerability to a disaster, the organisation of mitigation and recovery programmes, as well as evaluation of the need for investments in proactive protection measures, depend essentially on the expected extent of damage. However, much is as yet uncertain in this area. 'Damage' is one of the most controversial and multifaceted terms in disaster analysis; one rarely finds the same definition of damage in publications from different sources, such as authors, research institutes, or government agencies. The National Research Council, the US, provides a striking example (1999, p.5):

> "Somewhat surprisingly, however, the total economic losses that natural disasters cause the nation are not consistently calculated. Following a natural disaster, different agencies and organizations provide damage estimates, but these estimates usually vary widely, cover a range of costs, and change (usually increasing) through time. There is no widely accepted framework or formula for estimating the losses of natural disasters to the nation."

With little consensus on this key concept in disaster analysis, advancement of the disaster community can only be achieved by promoting an integrated approach where generally agreed concept definitions would form a basis. Here we quote Mitchell (2000) who notes, "Terminology that is confusing or contested can lead to misunderstandings, unwanted actions or protracted episodes of intellectual wheel-spinning". So, there is a

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[32] Cochrane (2003) uses systemic risk in a different context, which is related to the financial stance. Yet, both concepts are similar in nature.

need for a common set of concepts to achieve progress. Yet, in general terms, recently a convergence seems to emerge among scholarly authors in distinguishing two main elements of damage, direct and indirect effects (or higher-order effects, like suggested by Rose, 2004b), forming the core of the debate. However, many discrepancies still appear on the operationalisation and application levels. The difficulties experienced usually are threefold. Firstly, there is often no agreement on the common reference point. Here, such terms as public costs, private costs, insurance companies' paid compensations, and total economic costs – are in fact incompatible in a single comparison. Next, there is often no agreement on the scale of studies, be it temporal or spatial. Finally, sometimes no distinction is made between the stock and flow measures/dimensions of damage, which induces possible confusion between the concepts of direct and indirect damage. This, in turn, may lead to double counting, imposing a methodological bias on the estimations. We shall touch on these and a number of other issues concerning damage definition in this Chapter, outlining the multiple dimensions of the concept and challenges in addressing them.[33]

3.3.1. Who Are the Stakeholders?

The multifaceted character of damage clearly stems from the various purposes it is meant to serve. Who is in the end interested in damage and damage estimations in the context of a calamity? Evidently, there are multiple interested parties. First of all, governments are concerned with the actual and expected damage figures – for budget planning, investment arrangements, *et cetera*. This results from the fact that the task of providing public goods (also including their protection) is delegated to the government. Policymakers and planners should have precise damage data to be able to steer public policy in the desired direction. The Ministry of Public Works and Transport (the Netherlands), the Ministry of Agriculture, Fishery and Food, MAFF (the UK), the Federal Emergency Management Agency, FEMA (the US), and the Bureau of Transport and Regional Economics (Australia) are examples of such government organizations. ProVention Consortium, The UN International Strategy for Disaster Reduction (UN/ISDR) and the UN Economic Commission for Latin America and the Caribbean (ECLAC) are examples of international (intergovernmental) organisations, which carry out research on the natural disaster-related analysis for the purpose of policy implications.

Next, insurers, their associations, re-insurers and government insurance regulators have a high stake in information connected to damage estimation. Whether actual or expected, knowledge about damage is a factor of substantial importance to establish insurance premiums (which in some countries are regulated), which in turn have crucial influence on (the stability of) the insurance and re-insurance markets (see previous Section where we have outlined briefly the problems and specificity of disaster insurance, as well as discussion of insurance in Chapter 8).

Some industries are among the dominant stakeholders in disaster organisation systems. For example, the electricity industry will be interested in achieving continuity of its supply also during calamity periods. Some research in this direction has been done in Japan (Shumuta *et al.,* 2002; Yamano, Kajitani and Shumuta, 2004). Another

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[33] In addition, we refer to Bočkarjova, Steenge and van der Veen (2007).

example is the analysis of high-tech industry damages incurred after the Northridge earthquake in the US (Suarez-Villa and Walrod, 1999).

Clearly, individuals and businesses are another group of stakeholders in damage assessments. With this knowledge, decisions about private insurance and mitigation can be taken. Finally, academic researchers and experts in disaster analysis are the ones who are capable of providing this data, as well analysing it and, if necessary, supplying policy advice to governments. Here, the fundamental interest in the damage estimation and modelling stands to the fore of the development drive.

The parties which have a stake in damage estimation are each interested in a specific aspect. Governments are concerned with macro-finance issues, i.e., budget expenditures, which are affected by expected disaster damage figures. In this sense, government interest involves a broad spectrum, such as recovery expenditures, losses of taxes due to business interruption, increased number of benefits to be paid due to rising unemployment, and so on. Thus, ’state accounting‘ may be concerned, as expected increase in budget expenditures have to be balanced by new sources of income, such as for example, higher taxes. Alternatively, other state budget recipients, who would have otherwise been a priority, may become deprived because of government expenditures being adjusted in favour of disaster mitigation and recovery.

Private actors, such as insurers have a commercial interest, reflected in the value of claims to be paid under their policies. This covers direct damage to property and assets, as well as human lives (as mentioned before, the latter category falls outside the scope of this thesis). In addition, businesses will be interested to know whether they might be confronted with production disturbances. However, whereas the insurer’s insight into the possibility of a disaster is based on a probability calculation, that of businesses and especially individuals are based on individual risk perception (see, for example, Heems and Kothuis, 2006; Tatano, Yamaguchi and Okada 2004, and others discussing this issue).[34] Naturally, industry representatives are mostly interested in the performance of their particular branch. Finally, academic research in disaster analysis is formalised on the broad range of damage assessment. The additional aspect of damage which they are interested in is in particular economic damage, based on the concept of opportunity costs. We shall return to it in Section 3.3.3.

Summarising, each of the abovementioned parties will have a different perception about what damage means. Secondly, depending on the end user, various aspects of damage may be considered. Finally, the estimation of damage suiting the purposes of a particular stakeholder group could demand a special sort of methodology (for example, based on financial appraisal or economic damage estimation principles). We shall elaborate on this further in the following Sections.

3.3.2. Spatial and Temporal Dimensions of Damage

Just as the definition of disaster must be rooted in temporal and spatial scales, this also holds true for the definition of damage. In this Section we shall focus on two important dimensions of the concept of damage. In terms of *space*, depending on the area considered in the analysis, the amount of damage can vary, which is true both in an

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[34] This aspect will not be covered in our inquiry, where we focus on the insight into sustained damages in an economic system rather than on perceived damages.

absolute and a relative sense. For example, whether one limits the study of the consequences of hurricane Katrina to the city of New Orleans or the state of Louisiana, or even the federal level, the amount of damage will be different (because many areas outside the city were affected as well). Concurrently, this also applies to relative numbers, which are usually expressed by the loss of gross regional or domestic product, GRP or GDP. Whether we refer to the damage caused by Katrina in terms of regional or national products makes a substantial difference. The issue of the spatial dimension of damage hinges on the definition of spatial dimension of the economic system chosen for analysis of disaster, as we have outlined in Chapter 2. Whereas an ’economy‘ acquires its borders for the purpose of a particular study, this dimension can be readily applied to the determination of damage. The larger the area covered by an analysis, the larger the absolute losses, because in the contemporary globalised, interconnected world consequences of disturbances in localities may have far-reaching repercussions on the grand scale.

Another aspect of damage assessment is its temporal magnitude. Often, the effects of a disaster stretch out over a *time span* after the physical event took place. For example, buildings may collapse months after a flood or an earthquake, because their construction was undermined by the direct contact with water or due to ground movements. This means that attributing damage estimation to the point of time directly in the aftermath of a calamity is inappropriate. This only provides an estimate of direct vulnerability of a system to the hazard without considering the ability of the system to adjust in the face of a calamity. The relevant question becomes then: How long should the time span be to be taken into the analysis of disaster consequences? For example, the UN Economic Commission for Latin America and the Caribbean (ECLAC, 2003 p.12) suggests “convention calls for the maximum of five-year time frame although most losses occur during the first two. In any case, the estimate of these effects must be extended throughout the period required to achieve the *partial* or *total* recovery of the affected production capacity”.

The choice in favour of a broader time dimension is supported by the resilience argument presented in Chapter 2. We put forward that resilience is the response of an economic system to a perturbation in a way that it cushions the initial adverse effect of the shock and strives to achieve new balance, adjusting to the new conditions and disequilibria. During this process, a number of things can take place. For example, in the disturbed production network, where a part of firms temporary appear to be out of business as a result of a calamity, firms outside the affected area with spare production capacity can decide to increase their production, employing new opportunities and thereby acquiring a larger share of the market. Companies, which are able to switch quickly to new suppliers and customers, are able to resume production, keeping the overall production cycle running. This means that a so-called substitution effect is in place, which can be seen as one of the elements of a resilient economic system. In this way, domestic production substitution deflates the initial damage figures, contributing to the recovery of overall output. Yet, these processes are conditional upon the emergence of rigidities in the disaster aftermath, that we have discussed earlier in this Chapter (see Section 3.2.4), and to which we shall come back in Chapter 6 developing our model.

3.3.3. Economic versus Financial Damage Appraisal

As pointed out above, damage estimation serves various purposes, and it is therefore important to decide which particular purpose a particular study has. This will, in turn, affect the selection of aspects of damage one is going to evaluate. In this Section, we would like to stress again that there is a major difference between financial and economic appraisal. Below, we shall briefly discuss both.

Financial assessment is based, in the first instance, on the business balance sheet, which consists of two parts: Assets and Liabilities. Assets represent the value of all assets and resources at the disposal of the company in the given period of time; and liabilities reflect their sources. Assets include real estate, machinery and equipment, raw materials, stocks, as well as monetary assets like cash, money deposited on a bank account, and investments. Liabilities consist of capital (shares and reserves), and financial obligations such as bonds, and other debts. The main accounting equality holds: the total value of Assets is equal to the total value of Liabilities. This means that the costs of a disaster to a company would then represent a change in the value of a business as a whole, which then can be traced through a change in the total Assets and in the change of total Liabilities, which would show the same result. So, interpretation of one of those changes is enough to determine accounting loss.

The valuation in accounting terms as described in the previous paragraph is rooted in the depreciated value of lost assets (the so-called ’book value‘), which is obtained when the purchase value of an asset is decreased by the amount of depreciation. This allows for the gradual writing-off of assets and resources, spreading the costs over several periods of time. The costs of lost assets are then expressed in terms of depreciated value (for machinery, equipment, *et cetera*), which is the remaining value of an asset after depreciation at a particular point in time, and equals the balance-sheet value. This virtually implies that for example, a three-year-old machine should be replaced by the same old machine. It is important to keep in mind in this respect that the replacement principle for assets does not presume the purchase of new equipment. If it does happen, than the difference between the depreciated value of an asset and the price of a new asset that comes in its place is considered as an investment, not a loss.

An alternative approach to accounting is *economic appraisal,* which is based on the economic (opportunity) cost principle. Standard, alternative costs represent anything that has to be sacrificed to obtain some specific commodity or service. In this, economic assessment differs fundamentally from the financial approach. For example, a government may have to decide between two options of flood preparedness, like dike strengthening and a public campaign on raising flood risk awareness. The alternative cost of investing in dike strengthening in this case would be foregone investment in public campaigning.

Unfortunately, the concept of alternative costs is a complex one, and its application in disaster damage assessment brings many conceptual problems. Because assets are lost as a result of the hazard, we obviously have to do with the loss of resources. Losses due to a hazard are not a choice; i.e., there is no trade-off between various ends on which money could be spent (opportunity costs); it appears only in making reconstruction and recovery choices. This is a problem in itself: it is not straightforward how to define disaster losses in terms of alternative costs.[35] Because of this difficulty, the methodological underpinnings of the damage concept, and consequently damage estimation remain disputable. Yet, for existing markets, *market prices* are used in the valuation of goods and services.[36] We suggest that the same principle should be applied for the valuation of lost assets. By this we mean that the value of a lost asset is the market price of an asset with which the lost one is replaced. In fact, it is possible that a market for used equipment and machinery exists; which means that estimates of capital goods based on the replacement principle are very data-intensive (requiring an extensive knowledge of the state of lost assets at the time of a calamity). Yet, to simplify the estimations, we may also assume that only primary markets exist where new products are traded. This would imply that both a brand-new piece of equipment that is lost, and the one that is five years old, are replaced by a new machine at its current market price. Also, the lost real property is counted by the market value of the replacement property (either rebuilt or purchased instead of the lost one).

The analysis of damage as a consequence of a disaster should be based on either of the methods described above. A number of authors warn about the danger of mistaking the two principles (*inter alia*, Benson, 1997; Van der Veen *et al.*, 2003a). Researchers carrying out damage assessment should watch carefully that there is a consistent use of concepts in the appraisal, to ensure the reliability of their results. In this thesis we shall focus on the *economic damage* estimation, and therefore we shall continue with the techniques and methods describing it.

3.3.4. Economic Damage Assessment: Stocks and Flows

When conducting an economic appraisal of damage incurred within an economic system, it is important to make the essential distinction between two measures of asset value: stocks and flows. While stocks reflect quantity measured at a given point in time, flows reflect quantity per unit of time. Usually, stocks and flows are related. That is, stock is often considered as an accumulation of flows, and flows represent the change in stock (in a given period of time). Because stocks are often generated by flows, in economic theory it is generally accepted that a stock value of an asset equals the discounted value of future flows, generated by this asset. This has direct implications for the accounting of business interruption as a result of property loss. Economically speaking, one of the manners of thinking about the value of machinery or equipment used in the production of goods is actually considering the present value of all the goods the machine will expectedly produce during its lifetime. In terms of assessing disaster-imposed damage, this means that one can include either the market value of lost equipment, or evaluate the expected *flow* of output that will not be produced because the machine is lost. Consequently, including both measures can not be done, because they both represent the same value of a single asset. If stocks are counted together with flows

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[35] Only a few authors make it explicit, for example, Bram and Rappaport (2002) compare the development trend in the aftermath of 9-11 disaster with the projected trend without a disaster; while others (Rose and Lim, 2002) abstain from such an approach. Yet, in our view, it cannot be seen as an alternative cost, but rather as a threshold scenario.

[36] We abstain for a moment from considering damages to assets of exceptional cultural value (what is sometimes referred to as irreplaceable objects of art) or damages to nature. For non-market valuation methods, see *inter alia* Van Ast, Bouma and Francois (2004).

(for the same asset), one should guard against double counting (MAFF, 1999; Messner *et al.*, 2007). Thus, stock and flow values are only measures of the same category, not categories to be measured separately.

More than twenty years ago, Ellson, Milliman and Roberts (1984, p.559) concluded on the basis of their literature survey that "most of the economic impact literature fails to make proper distinctions between the measurement of loss and the measurement of long run patterns of personal income, employment, and population growth. Much of the research has confused stock and flow concepts in the estimation of loss. Double counting is often involved, and the losses are not estimated in present value term". This confirms that the issue of stock and flow measurement is at the core of proper damage assessment, and one has to pay a great deal of attention to this important issue.

However, if stocks and flows measure the same, which one of them should be preferred in damage assessment? We can look at the analysis of this issue done by Rose and Lim (2002). The stock of capital and machinery results in a flow of production and income in future, which means that business interruptions and capital stock affected measure the same thing. Rose and Lim (2002, p.2) state that, for several reasons, an estimate based on flows can result in a better estimate than estimating damage based on stocks, or property damage. Their reasons are the following: Firstly, an estimate based on flows makes up a better proxy of lost value, since it accounts for damage due to business disruptions. To this end, disturbances in business operations are not always attributed to the loss of stock (for example, industrial activities can be paralysed because of the failure in electricity supply), and thus flow measure takes consistently into account all business interruption that have effect in the economy. Secondly, flow measures are more compatible with macro-economic parameters, such as GDP, value added, and employment. Also, Rose and Lim (*ibid*) state that a stock based concept can result in an over-exaggeration of damage since only a portion of the property value may translate into service flows in any time. Thirdly, estimates based on a flow concept are more compatible and more consistent with the distinction between direct and indirect damage (we will address this later in this Chapter). Finally, flow measures require an explicit time dimension. This means, that economic modelling of losses should have well-defined borders. This becomes an important point of departure in the literature for the discussion of time dimension of damage, to which we shall also return in the following Sections.

3.3.5. Damage in the Literature

In this Section, we shall address the definitions of damage which are currently used in assessing the possible losses due to a natural disaster opening the debate on methodology developments for damage estimation. A number of studies estimating the consequences of a severe natural phenomenon, occurring in an industrialised economy, are now available. These studies, however, use different methodologies, partly involving different sets of concepts and definitions. Differences exist, e.g., in the treatment of direct and indirect costs (to be addressed later), the role attributed to substitution effects, and the statistical database. In addition, sometimes, concepts from the financial domain are used interchangeably with economic ones, often resulting in inaccurate assessments.

So far we have discussed various aspects of damage and damage estimation. However, we have not as yet defined what damage in economic terms precisely means. Let us first go through a number of terms that are used interchangeably with ‘damage’ to get to the essence of the matter. The report of National Research Council (1999) attempts to portray those most frequently used, mentioning apart from damage, such terms as impacts, losses and costs. In this thesis, we are talking about impacts and consequences that encompass a broad spectrum of effects. We shall use damage alongside the terms losses and costs when talking about negative economic impacts while exploring the literature on disaster analysis. In the literature we find a multitude of damage classifications: direct, indirect, primary and secondary, induced, second- and higher-order effects are mentioned. Moreover, the terms used do not always have the same meaning. With such variation, it is not an easy task to compare different studies consistently.

Cochrane (2004) offers a straightforward classification of damage in *direct* and *indirect* losses. He suggests (*ibid*, p.37) “Terminologically, indirect loss is any loss other than direct loss. Direct loss is a loss linked *directly* to disaster. It includes all damages, plus employment losses due directly to the closure of damaged facilities. Indirect losses are anything else.” This is a simplified view on the indirect costs that can be applied in the instances when total loss figure is obtained, and direct (physical) damages are known. Further, Cochrane offers more explanation on indirect losses (*ibid*, p.39): “Indirect losses are a result of dislocations suffered by economic sectors not sustaining direct damage. Activities that are either forward-linked (rely on regional markets for their output) or backward-linked (rely on regional source of supply) could experience interruptions in their operations.” Cochrane thus defines direct loss as the sum of physical loss resulting from the direct interaction of the forces of nature with human-induced environment, and the losses due to business interruption as those incurred by companies in the affected area[37]. Indirect loss, subsequently, can in fact best be described by the ripple effects throughout the economy, taking into account all production losses incurred outside the affected area. A number of American authors performing disaster analysis support this point of view, among others, Cole, Pantoja and Razak (1993), Cochrane (1997b), Chang (1998), and Rose and Lim (2002). We note that Chang (1998) follows Cochrane (1997b) defining economic losses, marking a convergence in opinion.

Another group of researchers, however, maintain a somewhat different view on the interpretation of direct and indirect losses. Thus, direct losses may sometimes include only physical damages; all losses caused by business interruption, both inside and outside the affected area, are considered indirect. Among others, Booysen, Viljoen and de Villiers (1999), BTRE (2001), Murlidharan and Shah (2003), and Messner and Meyer (2006) refer to such demarcation between losses. Parker, Green and Thompson (1987) agree, however they suggest a distinction between direct costs and primary and secondary indirect costs along this differentiation: Direct costs relate to loss of land, capital and machinery, therefore to stocks, and primary indirect costs to business interruption, a flow. Moreover, secondary indirect effects relate to multipliers in the economy. In view of the discussion between the measures of stocks and flows, the authors warn us that one can not add the first two categories (i.e. direct and primary

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[37] Cochrane (1997b) extends the definition of direct costs by not only including the physical damage to land, plants and houses, but also induced physical effects, which are the consequence of the disaster, and often referred to the disruption of lifeline system (discussed earlier in this Chapter) that causes additional business interruption (see also Tierney, 1997).

indirect costs) unless production is lost to foreign countries. This means that, in current terminology, for those assets that are involved in production processes, primary indirect and secondary indirect losses can be added to account for interruptions in the production circle; the loss of other assets can be accounted through direct damages.

For completeness' sake, another type of damage should be noted. Sometimes this is offered to analyse the macroeconomic effects of disasters (see for example ECLAC, 2003; Murlidharan and Shah, 2003; Freeman *et al.*, 2004; Mechler, 2004 and 2006; Linnerooth-Bayer, Mechler and Pflug, 2005). These often include stochastic modelling, macro-financing models and budgeting approaches. The ECLAC report notes however, that macroeconomic analysis acts as 'complementary statistics' reflecting the impacts of a catastrophe in terms of macro-variables, which should not be added to the estimates of direct and indirect damage.

A final remark about various types of damage can be attributed to Rose (2004b), i.e. the linguistic differences between the names of the concepts themselves used in disaster damage analysis. The main distinction is between the direct and the rest of the losses. As mentioned, these exist in a vast variety, such as, indirect, induced, primary, second-order or higher-order effects. Rose advances a proposal that, in order to avoid confusion between the disaster loss modellers, two terms should be used to distinguish between the major sources of damage, – direct and higher-order effects. This, according to Rose, overcomes possible misuse of input-output terminology and also is general enough to cover the effects illuminated by various models used in disaster analysis.

3.3.6. Weak Links in Damage Assessment

So far in this Chapter we discussed a variety of concepts connected to damage definition. At this point, we may summarise, that no widely accepted definition of damage can be found in the literature. This conclusion is based to the fact that, <u>firstly</u>, there is no agreement on the economic points of departure; financial appraisals are mixed with economic cost-benefit analyses (CBA). Where a financial appraisal is often the basis for investigating the sum of money to be recovered from insurance companies, CBA is a helpful means to weigh alternative measures against disasters. When the two are used simultaneously, methodologically inconsistent results are a consequence.

<u>Secondly</u>, there is confusion on the temporal and spatial scales. While financial appraisal limits itself to a single organisation, like a company or sometimes a state; economic analysis can be carried out at multiple spatial scales, ranging from local to regional, national or global. Here, choices have to be made. A similar argument can be made about the temporal dimension, where financial evaluations are tied to specified timeframes (like months, quarters or years). Alternatively, economic appraisals can be implemented for an arbitrary time frame, where it varies for the estimation of direct and indirect effects of a calamity. Each of these effects demands a specified time scale, which should be internally consistent within a single study.

<u>Thirdly</u>, there is the issue of double counting. This is often due to the confusion between stock concepts and flow concepts. We will give a further explanation, although this issue was already addressed in the previous Sections. The point is that the alternate use of stock and flow measures in one study is a common phenomenon, which has crucial consequences for the entire damage estimation. However, Rose (2004b) notes that the issue is not simple. According to him, "this is a controversial subject. I am in

agreement with analysts who suggest it is appropriate to include both the stock and flow measures in the case of damaged property, where the latter represents the opportunity costs of delays in restoring production." We can argue that, on the one hand, lost property can not have an opportunity cost because of the very fact that it is lost. It can be seen as loss of resources, which has to be accounted for based on the market value. On the other hand, one of the arguments supporting the assumption of a broader look on the post-disaster recovery can be found in Cole (1998, p.126) claiming that, in fact, disasters can also be viewed as part of the development process, providing opportunities, alongside with tragedy. In other words, a post-disaster situation may represent an entirely new state of affairs. It is characterised by new challenges, conditions and incentives for all economic agents facing the consequences of an adversity. This means that the post-disaster situation to some extent resembles more flexibility, as entrepreneurs, who lost assets as a result of a calamity, have to take new decisions, whether to resume production activities (in some cases, start everything anew), or not to do so. In this sense, lost asset can also be seen as a sunk cost because it can not be reimbursed in any way (except for insurance claims, which simplifies further argumentation), and therefore can not be taken into account in future decision-making. Based on these two arguments, we can say that there is no need to account for stocks and flows twice: lost assets are accounted for on the grounds of loss of resources. Delays should not be added to losses, as the new situation in the aftermath of a disaster brings also new opportunities offering a choice of resuming or opting for a new type of activity.

The other possible source of double counting is accounting for both loss of income and expenditure. Although this aspect does not come up often in the studies, we find it important to address this possibility as well. Cochrane (found in National Research Council, 1992, p.101, also cited by Chang, 1998), provides a thorough explanation on this account:

> "…the level of economic activity can be measured by counting expenditures, or incomes, but not both. Income […] must be equivalent to value of the products produced. This is because the price of a product reflects all the costs incurred in its creation, which in this case is the sum of wages, interest, and profits. This simple result provides an important loss-accounting guide: damage assessment should focus on incomes lost or spending lost, but not both. Either should yield the same result."

This statement should be borne in mind by researchers performing financial, as well as economic appraisals. Similarly, as we have stated in Section 3.1.3, financial appraisal should be based either on accounting for assets or on liabilities. This implies that from the point of view of financial loss assessment of lost stocks and profits are to be counted, while output loss should not. This means that one should either take a producer or consumer stand. Whereas producers are incurring spending for their inputs, wages, taxes, as well as foregone profits, all the consumers are loosing is the end product (which indeed serves a source of income for producers). Thus, accounting for final output loss is enough, and adding any other loss categories should be tested for double counting.

Next, loss definition suffers from the fact that in various studies the delimitation of the various categories of loss is unclear. As discussed, various studies use notions such as direct, indirect, primary, secondary, induced damage. Although lately, we also notice a trend towards the convergence to the direct-indirect loss division. Here, two main approaches can be distinguished. As we have demonstrated, some authors support the division of costs based on the spatial criterion (i.e., all losses attributable to the affected area are direct, losses incurred elsewhere are indirect), or based on the stock-flow differential (all physical damage is stock, and considered direct; all losses associated with production curtailment, whether within or outside the affected area, measured as flow, are indirect). In this, however, each scientist is free to choose; yet, provided that double-counting is avoided.

Finally, various purposes and destinations, as outlined in Section 3.1.1, that damage assessment serves are an obstruction to the wide cross-study comparisons. This means that we have to get things straight and establish a consistent economic loss definition to be used within the scope of this thesis.

We shall bear in mind the points of attention outlined above, while establishing a definition of economic damage to be used further in this thesis.

3.3.7. Our Definition of Damage: Direct and Indirect Loss

To avoid the ambiguities found in the literature,[38] we start by adopting the general framework of economic loss appraisal (which implies that the used key concept is economic costs as discussed above). We build upon the classification of economic loss by Cochrane (2004, p.37): "Direct loss is a loss linked *directly* to disaster. It includes all damages, plus employment losses due directly to the closure of damaged facilities. Indirect losses are anything else." Rose (2004b, p.17), in his discussion of direct versus higher-order effects, makes a similar proposition to use "the term 'higher-order effects' to cover all flow losses beyond those associated with the curtailment of output as a result of hazard-induced property damage in the producing facility itself." Based on these statements, we define:[39]

Direct losses are those damages, which are hazard-induced; indirect losses are incurred in the economy as a result of loss of interconnectedness and interdependence between agents within the predefined economic network.

Based on the MAFF (1999, p.15) views on double-counting, we relate direct losses to: physical damage to capital assets, including buildings, infrastructure, industrial plants, and inventories of finished, intermediate and raw materials destroyed

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[38] *Inter alia* the World Bank, the UN, IIASA and Swiss Re. See also for reference ECLAC (1991 and 2003), Benson and Clay (2000 and 2004), Freeman *et al.* (2004).

[39] We notice that in our definition, we distinguish between direct and indirect losses; yet, it is directly compatible with Rose's distinction between direct and higher-order effects. In our connotation, while direct physical losses are more 'visible'; indirect damages, like businesses impeding their operation and thus interrupting the circularity of an established economic flow, ironically enough, are not that apparent, while forming a substantial part of total losses throughout the economy. It is due to the 'latent' nature of indirect losses that inference about the working of the economic system is needed to bring them up to the surface.

or damaged by the actual impact of a disaster.[40] Business flows, which are interrupted directly as a result of physical disruptions, are also a part of direct losses. It is important to notice that the losses of assets in the disaster area involved in production activities give rise to what is known as business interruption, and, together with losses incurred by businesses elsewhere, which are in turn referred to as indirect losses, should be estimated in terms of disturbances of circular flow (which we described in Section 3.2.3). Formulating disaster damage assessment in terms of emerging concepts of vulnerability (or, alternatively, resistance as discussed in Section 2.3.4) and resilience, we have to take recovery into our appraisal framework as a part of medium-term effects; and adaptation as a part of long-term effects.

Besides, with respect to the MAFF definition, only that loss of output is considered which is not taken over by domestic producers. This means that MAFF takes the substitution effect on the (national) macro level directly into the definition of damage. However, because of the difficulty of accounting for the substitution effect as well as the multiplicity of other resilient actions at once, we prefer to distinguish between what we would call gross and net business interruption. Gross production loss in this context can be seen as the accounting of all losses in the immediate disaster aftermath (the extent of vulnarability). The net result for damage estimation is obtained when resilient response takes place and we can account for it. In the end, we define that:

On the macro level, only that part of non-produced output is lost (net), which is not taken over by domestic producers, and which is substituted by the goods produced abroad.

In other words, the proposition above suggests that, on the national level, any economic activity within the system that contributes to the decrease of lost output (e.g., using the spare capacities, or expanding the capacities reacting fast on the unsatisfied demand), should be seen as 'neutralising' initial loss. This would essentially mean that on the micro-level, there would be losers and winners; the former are those who were hit by the hazard, the latter are those who could take the advantage of new opportunities; on the macro level, those effects are added.

In this enquiry, we are most interested in the effects of disasters connected to the loss of connectivity within a complex industrialised economic system. This brings us to the type of damage attributed to the disruptions of flows of goods and services in such a system. In terms of defined damage, we shall concentrate on the business interruption as indirect effect in the entire economy. As already indicated, evaluation of such damage requires more than a survey of physical losses; rather, modelling of interconnections and interdependencies within an economic network is necessary. This means, that we have to pave the way to building a model that provides us with insight into these processes in the disaster aftermath.

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[40] We acknowledge the existence of non-monetary impacts, but we shall not provide an appraisal of those impacts within the scope of this thesis.

3.4. SUMMARY AND DISCUSSION

In this Chapter, we have gone into the discussion on the consequences of major disasters in industrialised societies. In contrast to developing countries, modern complex economic networks seem less predictable, in terms of both their vulnerability and resilience to a major hazard. In-depth studies of such systems are needed to gain insight into the processes behind a disaster.

In fact, modern societies with high concentration of wealth are faced with an additional challenge, which will expectedly trigger amplification of disasters in the future, i.e. the ongoing climate change. Extreme weather events, which seem to intensify through the time, are the biggest danger, and this has to be dealt within the broader context of development. We paid attention to the account of the consequences of a disaster in the modern economy. We identified three categories to be considered: scale, rigidities and the role of government.

We postulate that two types of rigidities can be in place that characterise an economy, namely, institutional and technological, which appear to become intensified in times of adversity. We focused on the description of structural rigidities pertaining to an economic system of production and consumption activities. Such rigidities can also be referred to as ‘bottlenecks’, a more familiar term in disaster analysis. Literature identifies failure of the lifeline systems (including infrastructure, transport and communications), full employment (in terms of lack of spare production capacities in an economy) and the emergence of the so-called ‘critical sectors’ as factors contributing to the creation of major bottlenecks for the reconstruction and recovery in the disaster aftermath. Clearly, institutional aspects of limited information, contract obligations, uncertainty, and so on, impose more challenges on the system and may also intensify technological rigidities.

Furthermore, we addressed the role of government in steering the post-disaster recovery and the issue of disaster insurance. Essentially, governments are expected, if not demanded, to provide at least some basic aid for disaster victims, as well as to provide a spin-off for reconstruction and recovery activities. This means, that for this underpinning modelling is necessary to suggest the directions to be followed, and measures to be chosen for launching recovery programmes. At the same time, the topic of insurance tends to reappear on the public debate agenda, while governments are increasingly willing to share the responsibility of risk management. However, disasters and major calamities are not common for the private insurance industry, as they are characterised by the presence of catastrophic losses, interdependence and ambiguity, all of which makes it troublesome for private insurers to define the amount of premiums, as well as to ensure the presence of capital to satisfy all disaster-related claims simultaneously. Here, a smart mix of private and public solutions should be sought.

In the final part of this Chapter we addressed the concept of damage, its purposes and definitions. The lack of consensus in the disaster community, which we noted in the previous Chapter, has direct implications for the conceptualisation of the damage notion. Essentially, we found that depending on the purpose served and stakeholders concerned, damage can have different contents. This has a reflection in the multiplicity of existing models and methodologies to assess damage. Because of the scope of current study, we concentrated on the issue of economic damage, which should have explicitly defined temporal and spatial dimensions. Moreover, we pointed out the clear distinction that has to be made between the economic and financial approaches, and the respective sets of concepts belonging to each of the categories. Finally, we also drew attention to the division of loss measures into stock and flow. This is in fact a crucial point to mark the so-called double counting of losses. We submit that caution should be exercised in accounting for interruptions in production processes (essentially interruptions of flows of goods and services in an economic network) that are characterised by losses associated with production still-stands.

To summarise, we propose, in the framework of this study, to use the division of damage into *direct* and *indirect* loss, – whether loss takes place directly on the site of the disaster outbreak, or outside of it. We also mentioned that losses connected to interruption of business flows in the affected area triggering production standstills elsewhere require a different way of accounting, compared to direct damages to the physical environment. For the latter, a type of statistical method can be used to assess the costs of lost properties, land and machinery (which is a stock measure). However, because of the complex interconnections within modern economic networks, which characterises contemporary industrialised societies, one needs an advanced model to trace the changes within these complicated systems and establish the value of indirect losses (which is also a flow measure). This means that we have to have a model to account for interruptions in the *circular flow*.

We have also tackled briefly the issue of scale of a disturbance and the relation between direct and indirect losses. As discussed in this Chapter, disaster consequences and therefore damage in the industrialised society are directly connected to the complexity of the economic system under attack. This means that we can assume at this point that because of the close interconnectedness of various elements within a system, any direct damage would most probably imply a relatively high extent of indirect damage. Because in the contemporary world system constituents depend on the array of conditions and the state of other constituents, major disasters are likely to push a system out of balance (and thus out of proportions), and thus to resonate far beyond the borders of their direct impact through a complex chain of avalanche effects. This means, that under these conditions we can expect that a major disaster in the developed economy would be characterised in particular by the intensity of the ripple or indirect production effects relative to the direct loss. The role of resilience in this situation is to neutralise indirect losses, adjusting in the face of a disaster; and through a-priori adaptation, to minimise direct losses, decreasing economic system’s vulnerability.

In the following Chapter 4 we shall discuss the possibilities for such modelling and make a selection of literature on economic analysis of disaster consequences before proceeding to the development of our own model (Chapters 5 and 6).

Part Two

Modelling

Chapter 4

Literature and Modelling

4.1. INTRODUCTION

In the previous Chapters we outlined the general framework for our research, i.e. the issue of large-scale disasters, which break out in an *industrialised society*, and their consequences. We aim at finding a way to describe in terms of modelling the economic effects of a disaster on society at large, as well as establish working definitions for a number of concepts frequently used in these analyses.

Chapter 3 mostly dealt with the debate on the effects of a calamity in a modern industrialised economy with a complex network of economic interconnectedness, and the definition of damage. We established that economic damage consists of two components, direct and indirect, and that it is defined on the basis of a distinction between stocks and flows. We found that we can recognize the difference between *measurement* and *inference*. Whereas direct damage estimation requires collecting data (which can be observed and measured to a certain extent) on physical disruptions, such as damage to buildings, equipment, and other physical assets, caused by the hazard itself, it is much more difficult to observe or measure the *consequences* of this loss - indirect economic damage, requiring more inference for an assessment. By indirect damage we mean the disruption of the circular flow of goods and services in an economic system, leading to the more complicated cascade effects in production and consumption markets. A temporary or persistent 'disappearance' of suppliers and/or consumers from an established system can resonate with significant effects on the welfare of society at large. To get a handle on these flow disruptions, we need a vision, a philosophy, and finally, a model, which could lead to the analysis of the processes in a contemporary economy, which evolve in the face of disaster threats. In this Chapter we hope to get closer to the core of our investigation, i.e. the literature covering economic loss modelling.

We already observed a number of problems in the field of disaster studies (tackled in Chapters 2 and 3 of this thesis). First of all, these are connected to the very existence of the field; there is a community of researchers, academics, experts and practitioners, basically in its early stages of formation. At the moment, this is characterised by a wide array of topics covered; concepts used and definitions applied, which in itself –perhaps–

may reveal a lack of a common methodological basis. In any case, all these factors make it difficult to compare, analyse and capitalise on the existing valuable knowledge; yet our goal is, within the scope of the current research, to provide an overview of studies dealing with economic modelling of disaster consequences. Highlighting the failures and advantages of each approach, we shall try to illuminate the features valuable to our fundamental inquiry, where we go back to the primary questions and basic principles underlying disaster analyses.

Yet, a number of features are shared by many scholars. Among these, we find the notion of the meso-level' as a most promising level. The typical macro-level of the national aggregates usually often is too abstract or too aggregated to be able to deliver the information sought for. At the same, the typical micro-level of the individual persons or agents may be too prone to accidental vicissitudes, which leaves the meso-level of investigation. One of the tasks then, to distinguish disaster modelling from other approaches and methods, is the representation of disorder and disequilibrium at a grand scale within an economic system in the immediate disaster aftermath.

Another feature is reflected in the choice of ‘rigidities’ that any model maker is confronted with. In our work, we shall focus on two types of such rigidities. The first one concerns technological rigidities as reflected in certain proportions between inputs and outputs in the technologies employed. This issue is also connected to the employment in terms of labour requirement, and the proportions in which final products are consumed by labour (that effectively comes from households). In particular, we shall consider here such ‘fixed’ or ‘invariable’ proportions regarding our consumption behaviour and our employment objectives. The second is of an institutional nature and concerns time lags, uncertainty, and so on. At the end of this Chapter, we shall put forth a proposal for a general framework to be used as a basis for extending disaster analysis in our study.

4.2. THE BODY OF LITERATURE ON NATURAL DISASTERS

In this thesis we have chosen to focus on the methodological issues of studying the economic consequences of major shocks in industrialised economies. This, in principle, implies that we are interested in the literature, which explores disaster impacts through a wide range of natural phenomena. For this purpose, we decided to be open to the studies of research conducted in various domains of natural disaster types, such as floods, hurricanes, earthquakes, or tsunamis (see for example Parker, 2000; Kunreuther and Rose, 2004). The selection of works below features perturbations that natural hazards bring to the economy, and the way the system responds to them.

In this Chapter, we offer only a selection of authors dealing with the analysis of consequences of natural disasters disturbing the interconnectivity within an economic network. We have to note from the outset that, due to the natural origin of the calamities we are studying, authors covering one or another aspect of disasters are split geographically. For example, British and Dutch researchers are more concerned with the issue of major floods, American authors cover mostly the effects of major earthquakes (although floods, hurricanes and other natural phenomena are studied, the scale of the events is not of the dimension we are looking for), Japanese scholars are exploring the impacts of earthquakes and floods caused by tsunamis. The scale of the event played an essential role in our selection. We are looking for analyses of a major hazard resulting in a vast disruption within a chosen economic system.

Not only the nature of a disaster, but also the purpose of the study make us distinguish various schools. We mentioned this in our discussion on the concept of damage. For example, studies concerned with practical issues, such as problem solving for a specific sector, are more ad-hoc oriented than studies focusing on the overall damage estimation within a specified economy. We aim at presenting an overview of the different approaches, picking up elements, where possible, that could be used in building our own model. As we shall see, these methodologies differ significantly in background philosophy, objective and scope. Eventually, some main lines will emerge, but by and large, the debate is just beginning.

4.2.1. Dutch Modelling Schools

We shall start with a discussion of recent modelling efforts in flood damage assessment in the Netherlands, reflecting the social science position in damage assessment. For a long time this aspect was continuously overlooked, in attempts to find engineering and structural solutions. However, it was discovered that little knowledge had been collected about the broader impacts, like economic and financial losses, loss of human life, environmental effects, and so on. This means that the quest for exploration of these aspects has just begun, and as yet is far from being laid down in a unique methodology; rather, depending on the kind of questions one wishes to address, different types of models are employed. Often, models in economic impact analysis focus on the micro and meso levels, without looking at the general picture of a calamity. In the framework of this thesis we are mostly interested in new research lines in the macro sphere, which pay attention to the issues of interdependency and interaction at the national level. As mentioned, we shall consider what happens at the macro level as a resultant of events at the meso and, sometimes, even at the micro levels.

A first model (or perhaps, ‘method’), which attempts to provide a methodological insight into the array of impacts, is the so-called ‘standard method’, developed by HKV Lijn in Water, a consultancy company, in a study for the Dutch Ministry of Transport, Public Works, and Water Management, MTP (Vrisou van Eck, Kok and Vrouwenvelder, 1999). This method is based on specific standardisations and is also used in the High Water Information System, HIS [41] (Meulepas and De Klerk, 2004; MTP 2005a), which provides information about high water developments in the primary dike [42] system to professionals and policy-makers. The method addresses various types of direct physical damage, as well as loss of life. It uses extensive data from the today available geographic information systems (see Appendix 5A for a description and applicability of GIS data), and detailed unit loss (or damage) functions for direct

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[41] The High-water Information System in the Netherlands is designed to monitor flood defences, to present inundation and loss calculations. Several stakeholder organisations are involved, with a central role for the Ministry of Transport, Public Works and Water Management (MTP).

[42] A few words of clarification are needed. Primary dikes protect the area against the ‘outside’ water, like the sea, the rivers or the lakes. At the same time, secondary dikes are found within the primary dike areas, which take care of the so-called compartimentalisation of the primary dike ring with the aim to limit the flooded area; under normal circumstances, however, they do not directly protect the area from flooding (see also Chapter 8 for more information on the Dutch water and flood management).

damage estimation. Each loss function includes three elements, namely estimated maximum damage per unit in construction category or productive sector; number of units in a category or sector, and damage factor for the particular category or sector. The maximum estimated damage value is determined by the replacement value of assets, which is effectively 'book value' (as we discussed in Chapter 3). The number of units per category or sector represents the number of buildings per respective construction category or number of establishments per productive sector. The damage factors are sector- or category-specific and vary according to the flood depth (e.g., the higher the level of flood, the higher the damage factor, and thus, the higher the damage incurred by the object). Damage factors in these functions are derived from simulations by means of hydrodynamic calculations and GIS maps based on a number of scenarios, taking into account the presence and strength of intermediate defences, differences in elevation and water levels, and building types. The method allows distinguishing damage factors for the following activity sectors: agriculture and recreation, pumping stations, means of transport, infrastructure, companies, and housing. Although providing a detailed account of direct physical damages, the method pays relatively little attention to indirect losses throughout the economy. In a recent version (see MTP, 2005b) the original classification of losses into primary direct losses, primary indirect losses, and secondary losses (Vrisou van Eck, Kok and Vrouwenvelder, 1999) has been replaced by a classification into two classes only: direct and indirect losses. Currently, in the standard method, direct material damage (substituting for primary direct losses) is defined as damage caused to objects, capital goods and movable goods as a result of direct contact with water. In the new version, direct damage due to business interruption (which replaces primary indirect losses) refers to losses due to interrupted production of businesses in the flooded area. Finally, indirect damage (replacing secondary losses in the previous version) is viewed as damage to business suppliers and customers outside the flooded area and travel time losses due to inoperability of roads and railways in the flooded area.

The method is not 'problem-free': "all the financial and/or economic consequences of a flood" (*ibid*, p. A-1) are assessed, which suggests that the separate notions of financial and economic damage are not strictly in contrast (see Chapter 3 for the discussion of theis issue). Also, double counting (also discussed in Chapter 3) may be a problem. According to the method, when direct and indirect losses are added, then both the costs of replacement of lost capital, *and* the loss of goods and services which are not produced as a result of production interruption at the production site are included. Following our earlier discussion, UK Ministry of Agriculture, Food and Fisheries (MAFF, 1999) suggests that including both categories can mean counting the same costs twice, as the first one (the costs of capital goods used in production) is a stock measure, and the other (the non-produced goods) is a flow measure of the same damage category. In addition, Eijgenraam (2005) points at another source of double counting resulting from the overlapping summation of direct and indirect losses when calculations are done for each dike ring separately.[43] If a summation of total losses in a

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[43] The part of the Netherlands vulnerable to flooding from sea or rivers is subdivided into a number of so-called dike-ring areas. Each dike-ring area is surrounded by a ring of natural or man-made water defences, such as dikes, dunes, concrete structures or high grounds. There are 99 such dike-ring areas in the country, including the ones along the Meuse (MTP, 2005c, p.13). A dike-ring area consists of one or more polders. One of the largest dike ring areas comprises the densely populated Western part of the Netherlands and covers important parts of the provinces of North Holland, South Holland, and Utrecht, and includes several major cities (Amsterdam, Rotterdam, The Hague, Leiden, Haarlem, Gouda). We

number of regions (dike rings in this case) is done, then it may occur that some of the costs that are direct in one region may be an indirect loss for another region, and vice versa, which means that a portion of costs is added repeatedly.

The Netherlands Economic Institute, NEI, (Briene *et al.*, 2003) presents a method to assess the maximum damage brought by a flood in a dike ring, including explicitly the calculations of indirect effects of production loss throughout the country. NEI follows the classification of damage in the standard method. Noteworthy is the manner in which indirect losses are estimated. In this, the NEI report refers to the underpinning study by the Tebodin consultancy group (Van den Berg *et al.*, 2000), which determines the maximum value of damage for various productive sectors. This, in turn, is obtained via the summation of the maximum values of buildings, installations and final products. NEI, based on the study of Tebodin, suggest that the inter-industry effects of shutting down part of a productive sector in the country are estimated in a way, which avoids the rigidity of the standard input-output multiplier. The authors argue that substitution effects, that take place outside the region (dike ring in this case) as well as the presence of suppliers within the region that are ready to take over lost production during the reconstruction period, are unaccounted for in the input-output national multiplier, and thus applying it would exaggerate the effects of business interruption. Therefore, only 25% of the indirect standard input-output multiplier effect is included in the business interruption losses. Furthermore, both Briene *et al.* and Van den Berg *et al.* do not account for the market value of the lost assets, but take the replacement value (after accounting for depreciation) as a threshold for estimating maximum damage (which is basically a financial concept).

The Dutch Central Planning Bureau recently published several studies on water management and policy assessment. In a recent study it presented a cost-benefit analysis rooted in economic welfare theory; an example is the analysis for infrastructural alterations of river courses: “Giving Space for Water” (CPB, 2000), with only limited attention to typical indirect effects. In two other studies (Ebregt, Eijgenraam and Stolwijk, 2005; Eijgenraam, 2005), the CPB presents a further developed methodology based on a cost-benefit analysis, focusing on the macro-economic level rather than standard damage calculations for a particular dike ring. This attempts to present a more complete picture of the overall effects between the constituent parts of the entire economic system. Eijgenraam (2005) discusses optimal safety standards for dike-ring areas. This study also contains a correction of Van Dantzig’s 50-year old contribution to solve the economic decision problem regarding the optimal height of dikes (Van Dantzig, 1956). Within the context of economic growth, the expected annual loss by flooding is the key variable. The Eijgenraam study provides the formulas for optimal investment in the heightening of dikes. The optimisation problem results in the minimisation of expected damage (which is based on the damage functions) and covered by the investments in the strengthening of flood protection defences to prevent damage. This optimalisation provides the economically optimal investment strategy. Software based on Eijgeraam’s approach, OptimaliseRing (Duits, 2006), provides the calculations for the moments in time when the investments have to be made, and what the amount of the investment should be. Furthermore, the software determines optimal flooding standards per dike ring as a function of time (in connection to this, see also the

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shall return to this issue and pay more attention to the discussion on the Dutch example of water and flood management in detail in Chapter 8.

discussion of current developments in Dutch water and flood management policy in Chapter 8).

We have seen that a number of studies are now available which focus, broadly speaking, on the micro- and meso-level. So far, macro-economic studies are relatively underrepresented. However, new research lines are pursued in several directions. An overview of damage evaluation methods as a result of a flooding is provided in the study of the Centre for Sustainable Development and Management team at the Erasmus University Rotterdam (Van Ast, Bouma and Francois, 2004). The report outlines ample possibilities for establishing the value of assets, and includes indirect monetary assessment strategies for non-market goods (like hedonic pricing, contingent valuation, contingent ranking and cost avoidance methods). Ultimately, the authors develop a so-called risk assessment approach, based on a discounted CBA framework, acknowledging the non-monetary damage aspects (e.g., damage to the nature and environment, emotional damage as well as uncertainty), and the risk perception of policy-makers.

The special point of attention for the Netherlands is the event of *large scale* flooding (either from the sea or the rivers).[44] A rising sea level and an increased probability of flooding of polders along the Dutch rivers and the coast demand a quick and permanent solution. We note, however, that there are relatively few reports on the consequences for Dutch society of a large scale flooding. Until recently, there have been several publications on small-scale inundations, but there was practically no experience with the societal and economic effects of major floods (Van der Veen *et al.*, 2001). In the broader international literature it can also be noted that the vast majority of scholarly work dealing with floods focuses on relatively small-scale events. This means that the authors are basically concentrating on the micro-effects of the events, producing cost – benefit analyses for the regional level. Large-scale floods analysed on a national level thus remain an issue, which is not covered.

Some recent Dutch work in the meso- and macro-sphere (Bočkarjova, Steenge and Van der Veen, 2004a,b; Van der Veen and Logtmeijer, 2005) concentrates on the effects of large-scale calamities in highly industrialized economic systems. Here, the case study of a hypothetical dike breach near Rotterdam (Krimpen) was studied, evaluating the effects of such an event for the entire Dutch economy. Van der Veen and Logtmeijer (2005) have tried to illuminate the so-called economic hotspots as a result of this hypothetical calamity, mapping those spots in terms of economic activity in the flooded area which would cause most of the (indirect) losses elsewhere in the country. Bočkarjova, Steenge and Van der Veen (2004b) offer building blocks for a three-stage procedure using an Input-Output based framework, employing a geography component for modelling economic impacts of major disturbances within an economy. An extended version of this approach is further developed and discussed in this thesis. The first stage, as the novel element in the approach, is to account for the immediate post-disaster situation, ‘disequilibrium’. When an essential part of a socio-economic network is suddenly ‘not available anymore’, this substantially undermines the ability of the entire economic system to function properly. The second stage follows, where looking for new

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[44] To illustrate the urgency of the situation, a single dike breach is enough to flood the Prince Alexander polder with the city of Rotterdam to an extent similar to that of the flooding of New Orleans after hurricane Katrina, where about 30 dike breaches took place (for more information, see Kok *et al.*, 2006). These findings also support the consequences of an imaginary Katrina in the Netherlands, see Dykstra (2005).

equilibria and design of recovery scenarios takes place. Basically, such a setting implies that one has to look at a complex system suffering a disruption as a whole, while it is trying to establish a new balance. This is accompanied by often extremely complex adjustments within the system itself, as well as the involvement of government in the recovery processes. With this in mind, it is important, not only to evaluate the possible damage that an economy can incur, but also to look at the possibilities for steering recovery. Clearly, a number of options exist and these should be studied as well. For example, the country may wish to re-establish the '*status quo ante*' as soon as possible. On the other hand, it may also wish to use the occasion to renew selected parts of its physical infrastructure. Finally, the model can be used as a basis for a cost-benefit analysis (CBA) platform for the evaluation of various policy options when the outcomes of multiple preventive measures and recovery paths can be compared.

The above-discussed methods present a picture of models and methods for damage estimation currently used in the Netherlands, their interpretation and justification. One characteristic to be noted is that the methodologies on economic cost assessment are still developing and are rarely described in detail. This is one of the factors which can explain the difficulty in comparing the various methodologies, also because the underlying concepts often vary in dimension. This means that it is not an easy task to compare the relative merits of the assessments provided by the different methods. At the moment, a multiplicity of partial studies are available, which, however, do not easily add up to a single picture. In future work, convergence to clear and possibly uniform definitions of the concepts, as well as an explicit choice of the modelling framework, is considered desirable.

4.2.2. International Modelling Expertise

On the international arena, often researchers tend to analyse natural disasters in the broader sense, taking into account the geographical, geo-technical, engineering, economic and even political aspects. This is due to the fact that initially studies of disaster consequences were dominated by the civil engineering field which focused on exploring the physical impacts of geological and hydrological hazards (which has also been the case in the Netherlands). Economic analysis started gaining importance later and therefore had to 'stream in' the established field of study, when it became apparent that broader perspective on disaster analysis and understanding of the processes and their consequences behind this phenomenon in modern societies are of great importance. One of the most vivid examples can be found in Scawthorn, Lashkari and Naseer (1997).

The study of Scawthorn, Lashkari and Naseer (1997) is an integrated approach, which, however, overlooks some economic insights, evidently an important element of disaster consequence analysis. In this research, a general outline of the disaster is drawn up, presenting the timing and scheduling of events. A study of hazard mitigation activities[45] is outlined on the basis of cost–benefit analysis derived from simulations of past disasters in the designated area. It is interesting to observe how the issue of supply and demand for structural protection measures against natural disasters is tackled. This involves not only financial considerations to provide additional safety, but also, and not

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[45] We recall that hazard mitigation, as defined by American scholars, contains actions directed at the reduction or elimination of risk, and includes both probability and consequence.

less importantly, sociological and psychological reasons for decision-making. For instance, Scawthorn, Lashkari and Naseer (1997) concluded that public demand for the civil protection and implementation of mitigation measures against earthquakes depends on the personal perception rate of such indicators as seismicity, seismic hazard and seismic risk.[46] This has led to the identification of a specific area in which public awareness has to be raised on the issue of natural disasters. Here, inquiries into the inferences alongside the measurement and their communication to the public prove to be an indispensable tool in a democratic policy-making.[47]

We note that the Scawthorn, Lashkari and Naseer (1997) study covers a wide range of physical impacts of disasters and mitigation strategies, without, however, explicitly engaging in modelling indirect economic effects of business interruption. This is evidence of the need of a special study into the modelling of broad economic consequences of major disruptions. Here, a number of approaches are available on the international arena, when one tries to gain insight into the post-disaster surviving capacity, thereby focusing on direct and indirect effects. These, as we defined in the previous Chapter, come about as a result of disruptions in sectoral purchases and inter-industry supply and demand imbalances.

First, let us note the efforts to determine the effects on businesses and economy in general on the part of national and international institutions and organisations (for the Dutch experience, please consult the previous sub-section). In this field, there are a number of studies. The report from the BTRE (2001) with the objective to establish the costs of natural disasters in Australia over time, to examine the trends in these costs, and to develop a model for the costs of future disasters, uses economic costs at the national level as a threshold for estimating losses. The Report notably refers to the fact that business interruption costs are deemed insignificant, provided there is production transfer between the producers. This is possibly true if a high level of resilience in terms of business substitution is present within an economic system (as we discussed in the previous Chapter); otherwise exclusion of this cost item from the total cost picture is not legitimate. The report however concurs with including losses associated with the increases of imports or decreases of exports. However, because the authors assume a high level of resilience in the system, no account of indirect business interruption losses is made.

Next, we refer to Benson and Clay (2004) with their report for the World Bank on the economic and financial impacts of natural disasters. In this study, the authors investigate the fiscal constraints to and implications for economic growth, development, and poverty reduction, with particular focus on developing countries. The study adopts what is called an eclectic approach that is based on the construction of a historical narrative of disasters for the country or region of the case study. According to Benson and Clay, disasters are not treated as a ’black box‘, i.e. external negative economic shocks,. A mixture of formal quantitative and qualitative analysis is employed to

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[46] An array of literature can be found dealing with the issue of individual risk perception, which is one of the critical issues for policy-makers (see, for example, Plough and Krimsky, 1987; Baker, 1990; Eiser, 2004; Kaiser and Witzki, 2004; Tatano, Yamaguchi and Okada, 2004; Heems and Kothuis, 2006; Messner and Meyer, 2006).

[47] See, for example, the Report of the Dutch National Institute for Public Health and the Environment (RIVM 2003, p.14), which suggests that in cases where the risk of some events is characterised by complexity and high consequences, the choices concerning acceptable levels of risk should be discussed in an open public debate.

examine the economic impacts of natural hazards at an economy-wide level, where quantitative investigations are partial, involving a combination of regression analysis, the use of charts to examine movement around trends, and ’before-and-after‘ comparisons of disaster impacts, such as the forecasted and actual economic performance. Interestingly, the authors use a null hypothesis, which implies that there is no direct link between disaster shocks and economic performance. A qualitative political-economic analysis is complementary to place quantitative results within the specific economic and social policy context of each country in the case study. By disconnecting the disaster event from overall economic performance, the authors are, however, obliged to explicitly reject their null hypothesis before alienating the effects of a calamity - which can be a justifiable approach to study developing countries where adversities occur frequently, and virtually are part of the development trend.

The UN Economic Commission for Latin America and the Caribbean, ECLAC (2003), and the British Ministry of Agriculture, Fisheries and Food reports (MAFF, 1999, 2000) offer broad and rather detailed frameworks for disaster consequence appraisal, but provide no unified model. The former covers in its analysis such aspects as social sectors, infrastructure, economic sectors (like agriculture, manufacturing and tourism), and other factors (including environmental and macroeconomic effects). The latter is in effect a cost-benefit framework for the appraisal of flood and coastal defence projects, including damages to property, infrastructure, indirect business losses, non-monetary losses to households, as well as recreational and environmental values, comparing costs and benefits of specific measures to the so-called ‘do-nothing’ option.

Macro-models, however, are available, for example from the International Institute for Applied Systems Analysis, IIASA, Austria (see Freeman *et al.*, 2004; Mechler, 2004; Linnerooth-Bayer, Mechler and Pflug, 2005). The model, as outlined by Mechler (2004), consists of three elements, and analyses the macroeconomic trade-offs in natural disaster risk management, assessing the macroeconomic costs and benefits and cost-efficiency of management measures. The model integrates probabilistic natural hazard losses into macroeconomic planning models. In its first step, the model translates the direct losses into macro-impacts in terms of flows. Secondly, the insurance module analyses different (re-)insurance strategies for the insurance of infrastructure by the public sector. Finally, risk management is assessed by means of a CBA. However, little attention is paid to the economic and production-related structure of a system under analysis with impacts on the meso-level.

The models and approaches outlined above are all having the macro-scale as the focus of their studies. Alternatively, if we adopt an approach based on the sectoral level, a number of other methodologies are available. Input-Output Analysis (I-O) and Computable General Equilibrium (CGE) are well-known approaches. Both types, however, traditionally have their typical advantages and disadvantages. For example, because standard input-output theory is often seen as rigid in terms of its technological ties and thus less appropriate in situations where substitution possibilities present themselves, input-output based methods have been viewed as being the less evident choice if market-based mechanisms play (or should play) an important role in the processes under study. On the other side of the spectrum, CGE methods, allowing instantaneous price adjustments, have been characterized as being overly optimistic regarding market flexibility and overall substitution tendencies when confronted with real world adaptive (in)capabilities (Rose, 1995, 2004b), often restricted in the immediate disaster aftermath and later recovery (we pointed out at these issues in Section 3.2.4, Chapter 3).

Rose made a significant contribution to the development of disaster-related modelling in I-O, as well as in CGE paradigms. With his conceptual works (see Rose and Lim, 2002; Rose, 2004b) and particular the discussion on resilience (Rose, 2006) which we introduced in the two previous Chapters), he continued his work in modelling economic consequences of adversities. The focus of a number of Rose's modelling effort contributed to the understanding of the influence of lifeline disruptions caused by a hazard on the interrupted economic flows and their repercussions throughout an entire system (see Rose and Benavides, 1998, on electricity lifeline disruption analysis, and Rose and Liao, 2005, on water service disruptions). With the help of specified impact coefficients, disturbances in other productive sectors were modelled within an input-output framework as a result of electricity system breakdowns. However, the investigation was carried out at the county scale, which does not correspond to the magnitude of events we are looking for. This means that for our inquiry, we can use the elements of his approach, although we would have to adjust them for the larger scale of an event in our study.

In a number of studies, Rose (Rose, 2004a; Rose *et al.*, 2006) paid attention to the analysis of resilience and mitigation. In Rose and Liao (2005) and subsequently in Rose (2006), a CGE approach is used to study resilience and its quantification for cases of major disruptions, viewing the economic system's capacity to react to adversity. However, the authors acknowledge that without further refinement, CGE models, as well as nearly all other economic models, reflect only 'business-as-usual' conditions; while disasters and other extreme major disorders are discontinuities, and therefore may make a system reshaped in a different sort of pattern. Rose and Liao developed modeling improvements advancing the CGE analysis of major supply disruptions of critical inputs by specifying operational definitions of macroeconomic resilience (which include water and other input conservation, increased substitutability of other inputs for water as a critical resource, back-up supplies, time-of-day usage and change in technology), linking production function parameters to various types of producer adaptations in emergencies, developing algorithms for recalibrating production functions to empirical or simulation data, and decomposing partial and general equilibrium responses.

In their research, Rose and colleagues came across the issue, and justifiably raise this in their work, that in effect any model used for an analysis of changes in 'normal' circumstances has to be adjusted for an analysis of events of major disturbances. This is very important for disaster studies, as it points to a serious gap in existing modelling practices and the need for methodological advancement. The lack of development of methods for economic disaster consequence analysis evidences the need for our current study. The fact that Rose and colleagues raise this fundamental issue only substantiates our attempt to find an adjusted, well-structured and transparent methodological framework for major calamity description, analysis and exploration of recovery and preparedness actions and policy.

Persistently, Rose (1995, p.296) reveals: "My own use of CGE models has increased my appreciation of input-output economics rather than diminished it." This statement is a witness to the usefulness and importance of the input-output approach in contemporary modelling, despite its, sometimes misperceived, drawbacks (for more discussion of this issue, see further Rose, 1995). In the following, we shall concentrate on input-output analysis. One reason for doing so is that the model remains attractive for the assessment of costs incurred by a disaster as it offers a simple way of accounting for a complex economic system. Another reason is that it seems a better tool for analysing situations of severe disruptions because it allows us to concentrate specifically on the physical side of the problem at hand. This means that, on the one hand, as a complete and internally consistent accounting system, it should be able to make the connection between the physical disruptions in the immediate calamity aftermath, and map them into the input-output 'accounting' tables. Our main point, however, is that input-output is underutilised or underdeveloped as a methodology in dealing with disruptions and imbalances of the type we are discussing. Input-output methodology, as it stands now, does not offer a very flexible set of tools to deal with such situations. The problem here is (partially shared with CGE methodology) that it stresses interaction and equilibrium, while the post-disaster situation, as we discuss it, is characterized by severe disruption, often chaos, and consequently, disequilibrium. In situations where the economy is suddenly confronted with an entirely new set of circumstances, with hazard-imputed consequences, where it has to act quickly, and has to make decisions in a non-standard way in the light of suddenly restricted or unavailable resources, input-output, as it stands, is essentially inadequate. Our approach proposes that a return to *basic principles* is needed to give it its due place and scope, and to extend to major shock analysis.

4.2.3. Input-Output Modelling in International Disaster Literature

Many authors have chosen inter-industry input-output models for analysis because of their ability to reflect the structure of a regional economy in detail and to trace economic interdependence between the regions by calculating indirect effects of disruptions, as if one was 'localising' the disastrous event. The use of these models to estimate the regional impact of natural hazards dates back to work by Cochrane (1974). Later, in his study of the economic impact of an earthquake in the American Midwest, Cochrane (1997a) suggested an inter-industry model as a means of measuring indirect loss. The approach used by Cochrane (*ibid*) relied on both the existence of regional input-output tables and several assumptions on inventory management, importability of shortages, exportability of surpluses and the amount of excess capacity in each sector, the output of each sector consisting of a fixed proportion of other sector outputs. Cochrane provided an analysis of the relation between direct and indirect losses, focusing in particular on the dependence of the relative magnitude of indirect losses. As a result of a number of simulations with varied user inputs and damage patterns, an emerging pattern was observed, about which Cochrane (2004, pp42-43) concludes: "Indirect loss […] is less sensitive to economic structure (manufacturing dominated or service dominated economy) than to damage pattern, degree of integration (size), preexisting conditions, and who is financing the recovery." This means, that the relative magnitude of the economic system, the system's vitality (which is directly connected to the concepts of adaptability and resilience discussed in Chapter 2), asymmetry of the shock, and recovery planning are central to the understanding of processes behind the disaster event in modern economies. The study of Cochrane is a valuable contribution to the understanding of the consequences of major disturbances on the generalised level. However, there is no additional insight into the structure of an economic system and an analysis of changes thereof. This means that the analysis performed does not provide a more detailed perspective on disaster phenomenon within a complex industrialised network, which we are studying.

Continuing with the literature overview, we should note the HAZUS software, a multi-hazard loss estimation methodology, developed by the Federal Emergency Management Agency and the National Institute of Building Sciences (for detailed description of the software, see (FEMA, 2001), where both Rose and Cochrane were among the contributors). This is based on the data from a geographic information system and is intended to simulate the direct and indirect economic effects of a specific natural hazard, like an earthquake, flood or wind storm. The HAZUS algorithm is essentially I-O based, though it is neither a linear program, nor a CGE model. Let us clarify: within the HAZUS setting, it is assumed that household spending is endogenous, thus favouring type II input-output multipliers. With the specification that households behave according to the Life-cycle model of consumption (assuming constant average consumption through the years based on the total income earned), the pattern of consumption is disconnected from regional income at a particular point in time, and thus remains constant. Although the algorithm does adjust trading patterns, it does not allow for product and input substitutions driven by relative price changes, thus keeping the model more transparent, and the results easier to interpret relative to CGE.

The Indirect Economic Loss Model (IELM) component of HAZUS uses the post-disaster surviving capacity in terms of a part of surviving production as a starting point for recalculating inter-industry supplies and demands. This is done as follows. The algorithm determines the impacts on the inter-industry sales and purchases by means of row- and column-wise multiplications of the transactions table with the factor of survived capacity. Following this procedure, first inter-industry inputs are multiplied (input-output transactions matrix columns) by the respective percentage of the sector's post disaster capacity; then shipments (input-output transactions matrix rows) are multiplied by the surviving capacity. Finally, the algorithm adds the pre-disaster final demands (household, government, and exports) to arrive at a complete measure of excess supply and demand by sector. The algorithm of the module then identifies and balances the shortages and excesses. If excess demand is detected, the algorithm searches for a way to adjust sectoral capacity to account for unemployed resources in the region, and by importing from other regions, which are user-defined. If excess supplies are detected, the algorithm searches for alternative means of disposing those supplies, specifically through export. The model adjusts potential outputs iteratively, depending upon the unique characteristics of the economy under study, until all net excesses are eliminated.

The strength of the software is that it represents one of the most complete methods to model *ex-ante* and ex-post disaster consequences in an integrated manner, with an explicit geographical component. However, the model hinges on a number of specific assumptions. Unusual for an input-output analysis is the treatment of rows as columns of transactions matrix according to the surviving production capacity, while resulting coefficients and multipliers are interpreted in the conventional input-output sense. The reason is the assumed stability of technological coefficients (see also Rose and Chen, 1991), i.e. column-wise proportions within each sector; that's why, if the input-output transactions matrix is also multiplied row-wise, vertical proportions become altered and need new interpretation or modification.

Cole contributed a great deal to the development of input-output techniques applied in relation to earthquake analysis. Cole, Pantoja and Razak, (1993) used economic models based on social accounting matrices (SAMs), which are effectively extensions of conventional input-output tables and often cover additional income and expenditure flows between institutions, such as households, government and the rest of the world,[48] to measure the consequences of planned and unplanned economic events in small island economies. These models were constructed on the basis of past disasters, and simulative models were produced for the specific areas most prone to the impact of natural hazards. The approach offered by Cole, Pantoja and Razak uses a so-called Event Accounting Matrix (EAM), whose elements correspond to the entries of the SAM. Such a matrix is constructed so that it enables the mapping of the direct impact of the disaster onto the SAM. Following Cole (1998, p.135), the EAM records the intensity of the impacts on each activity and transaction in the first instance, and the response (or recovery rate) of each activity or transaction after a disaster in the second instance. With the help of an EAM, a system's vulnerability and adjustments can be modelled, and the results can be used to design strategies for regions prone to natural disasters (we shall return to the EAM idea in Section 4.3). The authors suggest that such a technique can be developed further into a full-fledged expert system for use in post-disaster economic recovery efforts, which could in turn provide a framework for the integration of a sector-specific expert system in transport and water supply systems and other activities in the public and private sectors. The discussion on the use of expert systems versus decision-support systems in policy-making was continued in Cole (1998).

In his following studies, Cole (2004a,b) proposes a model to analyse how disasters and their consequences affect social actors and propagate throughout society. The focus of these works of Cole is the preparedness for disasters and survival strategies, which should improve societies' capacity to face adversities and recover from them (found also in Cole, 1995). Essentially, the suggested model hinges on investments in protection as a 'buffer' saved for the case of calamity. Purchase of formal insurance, maintenance of stocks, provision of a duplicate water supply system or even maintenance of social networks can be seen as investments; at the same time, these precautionary measures come at a cost. The opportunity cost of the resources used for investments in the 'buffer' cannot be put into production, increasing welfare in business-as-usual times. In more technical terms, *ex-ante* preparations and spending on protection are 'leaking out' of an input-output table, and in effect remain idle (as they cannot be used for other purposes) before disaster strikes. This means, that investments in preparedness can be accounted for in a special added row (as costs) and column (as sources) of a SAM matrix.[49] With this additional account, a SAM becomes what is called an insurance accounting matrix. When modelling the post-disaster situation, the benefits of precautionary investments in terms of lower costs and faster recovery can be identified. Then, these benefits can also be weighed against the costs incurred, but also against the ripple effects which are not realised because part of resources were taken out of the system for the sake of protection. The suggested approach allows a demonstration of how contingencies and protection in one sector or in one segment of society can

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[48] The SAM provides an insight into the link between input-output tables and the so-called sector accounts, which include factors and institutions. The SAM particularly focuses on the representation of consumption and factor remuneration. Also, the activity part of a SAM is identical to the input-output table, although the level of aggregation is usually much greater. Differences between the other parts of a SAM are substantial, however. This reflects the diversity in purpose among users of the SAM.

[49] In his works, Cole widely makes use of SAMs, Social Accounting Matrices, which are an extension of a standard input-output table, constructed based on the same double-entry principle, and include a variety of additional information. For example, Cole builds his studies of small island economies around SAMs, accounting for the segmentation present in the society, like the division between the rich and the poor, modern and traditional sectors, public and private sectors. Adding the new information to the standard input-output table, one can see the specific pattern of income and expenditure per group, and thus analyse which effects calamities can have on each group. This can be a very useful exercise for cases where differences between social strata and sectors comprising economic network are substantial.

affect vulnerability of another, as well as to examine the optimal level of protection investments to be made.

Another input-output based model on the international arena is one presented by Santos and Haimes (2004). Santos and Haimes offer what they call the inoperability input-output model for studying the disturbances due to a terrorist attack. Within an input-output framework, the authors use decomposition analysis to arrive at the description of how terrorism-induced perturbations can propagate throughout an entire economic network resulting from system interconnectedness. In essence, inoperability, as defined by Santos and Haimes, refers to normalised production loss, where decreased production due to a disturbance is related to the 'as-planned' production level. Ultimately, an input-output type equation is obtained, which is an alternative representation of conventional output-final demand modelling. The model uses a Ghosh-type coefficient matrix, which is, essentially, the supply-side input-output model (see Chapter 5 for a more detailed description of the standard input-output model, as well as Ghosh, 1958; Miller and Blair, 1985). It relates the (normalised) inoperability output to the demand-side perturbation that is also normalised according to the 'as planned' output level. The model is an example of an input-output modification for calamity modelling, although does not include a discussion of the essence of perturbations. Although the model is meant to shed light on the processes in an economic system in the wake of a calamity, the model operates as a usual equilibrium artefact, not accounting for the mismatches and imbalances in the economic network brought about by the major shocks.

Finally, we would like to outline the joint works of Okuyama, Hewings and Sonis (2002 and 2004), built around extending an input-output model with a time dimension. In addition, the dynamic character of the introduced Sequential Interindustry Model (SIM) allows the adoption of production chronology of various production sectors (divided between anticipatory, responsive and just-in-time modes) to model the impact of the unscheduled events, as well as recovery and reconstruction thereafter. The model is developed for both single-region and the bi-regional settings (using input-output table for two regions). The just-in-time sectors (mostly, services) are characterised by the conventional input-output equation, whereas input-output equations for anticipatory and responsive sectors are modified. The anticipatory mode (represented by agriculture and most of the manufacturing industries) provides the dependence of current period output on future (anticipated) output and current final demand. The production of a sector in the responsive mode (construction industry) depends on past output and current demand. Providing the implications of this analysis for recovery and reconstruction, the authors conclude that inventories and the availability of perfect information play a significant role in analysing the surprise aspect of an adversity on output fluctuations in the disaster aftermath. One cannot prepare for an unexpected, unanticipated shock, which means that high losses may follow. As a result, the model shows that mismatches between demand and supply as a result of fundamental perturbations within an economic system in a short period of time are unavoidable. Essentially, the model proves to be valuable for disaster analysis and subsequent recovery over time. On the one hand it is capable of providing insight into the recovery phase-wise planning to avoid bottlenecks; on the other hand, it may also be used to identify those temporal key sectors, crucial to the economy-wide recovery. However, the model does not pay a great deal of attention to the infusion of the shock itself, which is done through the decrease of final demand.

Looking at the methodology used by researchers on the international arena for economic disaster analysis, we can conclude that the methods, which incorporate input-output and SAM techniques vary among authors and provide us with a vast range of information for consideration in our studies. Experiences with manipulation of the input-output model and its extensions in the attempt to model post-disaster recovery show that existing approaches are as yet incomplete, and that improvements are certainly called for.

4.3. ANALYSIS AND CHOICES

In the introduction to this Chapter we stated that disaster analysis as a community of researchers, practitioners and academics is still taking shape, and that therefore generally accepted theoretical and methodological bases are still missing, in contrast to more established fields of study. This is one of the underlying reasons why research efforts carried out all around the world in the scientific community are spread so widely, both in method and purpose, which complicates the detection of a common denominator. The evolution of the disaster research community indirectly triggered the emergence of multiple approaches and schools. We have attempted to make a selection from these, which we present in this Chapter.

In the remainder of this Chapter, we shall elaborate on those elements in disaster consequence analysis that seem promising to use in our own modelling. After this, there will be a discussion on the choice of a basic modelling framework. We shall conclude this Chapter with a summary.

4.3.1. Literature on Methods and Models

Needless to say, much valuable work has been done in the field of disaster impact modelling. However, much of it has been devoted to the study of particular empirical needs or cases (Shinozuka, Rose and Eguchi, 1998), where the electricity system blackout consequences after an earthquake are analysed; or serves specific practical purposes (Tierney and Nigg, 1995; Freeman *et al.*, 2004). Tierney and Nigg (1995) emphasise that lifeline service interruptions after the 1993 Midwest floods were perceived by businesses as very disruptive, and were a much more significant source of business closure than actual physical flooding. Freeman *et al.* address risk management in terms of macroeconomic planning, i.e. the incorporation of potential future natural disaster losses into current budgeting activities. The nature of the problem at hand often forces the researcher to develop specific methods for case-oriented problems, while wider theoretical and methodological aspects had to remain invisible. For example, in her study, Chang (2003) develops a methodology for cost-benefit analysis of disaster mitigation measures for urban infrastructure systems with the emphasis on evaluating societal impacts. This should be seen as an important contribution to the field of disaster studies, as Wisner and Luce (1993) point out that very often the emphasis of analyses is on the physical hazards, not human vulnerability, which Chang successfully fills in. In the current analysis we shall take a conceptual standpoint, returning to the main concepts behind economic disaster modelling, yet taking into account the 'human side' of a catastrophe. This can, we hope, connect applied studies and methodological advancement in the field.

The literature suggests that it is essential that, as soon as possible, it becomes clear what exactly has happened, and how the situation has changed *immediately after* the disaster. Evidently, a disaster, by definition, brings about a shock to an economy of an unprecedented scale, and thus marks a break in the established development path. The severity of an event, together with a lack of familiarity with similar events in the past, gives little room for experience for both economic agents and decision-makers to react quickly and appropriately to an adversity. This is one of the reasons for the failure to perform and respond effectively to the tragedy in New Orleans after the devastating hurricane Katrina in 2005 (see US House of Representatives, 2006; as well as Ink, 2006; and Menzel, 2006). Among others, Penner (2006, p.1) explicitly states: "Katrina spectacularly exposed widespread weaknesses in the public policy response to catastrophes, weaknesses that afflicted everything from the humanitarian response to the operation of the food insurance programme." The studies on the effects of Katrina witness an agreement on the fact that the calamity came unexpectedly; no one seemed to have anticipated neither the event, nor its scale and strength of impact. This means that such (perhaps, virtual) experience should be built up in advance by modelling, simulating and analysing possible disaster events as well as drawing up scenarios of expected damage with potential recovery possibilities. This is essential in putting recovery programmes into place and in reviving prime activities after the factual systemic shock. We can draw from this that disaster preparedness aspect is essential, and it is important that disaster modelling frameworks are able of providing good *ex-ante* analysis to support policy and action.

However, modelling and analysing an economy under stress is not an easy task. The literature (Okuyama, 2003b; Van der Veen *et al.*, 2003a; Cochrane, 2004; Rose, 2004b) seems to agree that a precise starting point for disaster research is often missing. Even where it is assumed 'obvious', the basic issues of disaster implications always require additional attention. For example, there is no accepted formula for the representation of disrupted ties within an economic network as a result of a disaster. There is also little clarity about the recovery goals, and in many cases returning to the pre-disaster state (what is referred to as 'normalcy', see for example McEntire (2006) becomes a common strategy, while other options are often left unconsidered. It becomes clear that in the first instance there is a need for proper understanding of the post-disaster situation. Okuyama (2003b, p.12), e.g., notes the uncertainty that appears as a result of a disaster:

> "Uncertainty arises after a disaster because first, the extent and range of direct damages are unknown right after the event; second, the trends of economic activities, especially the fluctuation of demand, become unclear in the short run; and third, the influx of demand injections for recovery and reconstruction activities makes the long-run forecast of economic growth in the region difficult."

In our approach, we want to stress the importance of starting from the basic need of an adequate reflection of post-disaster survived production capacity in an economy. There is a range of attempts at pointing the way for economic modelling of the disaster aftermath. A set of three factors can be distinguished which basically stipulate the track of post-shock development: *the level and severity of the damage incurred*, *the economy's resilience potential*, and *the external factors* (for a discussion of resilience, vulnerability and related notions, see Chapter 3). Cochrane (1997b, pp243-244) points out that combinations of similarly defined factors trigger the recovery direction of each particular economy to a (new) equilibrium, and stipulate the ratio of gains and losses of a shock brought about by a disaster.

Other authors, e.g. Rose and Lim, (2002, p.12) discuss a similar issue whereby preconditions can pave the way for an economy's survival capacity after a calamity and point out that "More sectorally diverse economies are better able to withstand the shocks of business interruption losses". Adger (2000, p.352) contributes to this discussion, adding that promotion of specialisation in economic activities has negative consequences in terms of risk to individuals and for communities. We can interpret the argument behind such reasoning to mean that specialised economies are less resilient to major shocks, as they rely on few areas of specialisation and are thus less flexible in risk distribution. Specialised economic systems can exhibit a greater risk of failure in case the resource or industry(ies) it relies on are gone. Furthermore, Adger *et al.* (2005, p.1037) suggest "in social systems, governance and management frameworks can spread risk by diversifying patterns of resource use and by encouraging alternate activities and lifestyles." However, before studying prevention, one has to understand the mechanisms of a disaster in a modern economy.

Here, we start with Cole, Pantoja and Razak (1993), who, recapitulating the situation in an economic network immediately after a calamity, introduce what they call an event accounting matrix, EAM (see also the previous subsection). This is one of the comprehensive efforts to try to realise and manage the recovery of an economy in a disaster aftermath in a systematic manner.[50] The aim of establishing an EAM is to bring structure and transparency in thinking about the disorder induced by a calamity, and to provide a direction for recovery planning, for which the authors confirm its importance in economic disaster analysis.

The specific focus of Cole and colleagues on relatively small (island) economies like Aruba and their preparedness for destructive natural phenomena can be deemed to be related to the character of the problem at hand. Essentially, the relative dimension of disturbance at the core of Cole's attention is crucial and therefore an analogy can easily be drawn to our study of a large-scale calamity in an industrialised economy. Due to the location of the island in the Caribbean basin, it is quite susceptible to a natural hazard; due to the relatively small size of the country, Aruba is also relatively vulnerable to hazards. For example, the island is completely dependent on tourism, which in turn is sensitive to natural hazard events. This means that even a moderate natural adversity can cause significant harm to the functioning and endurance of the entire society. In their modelling effort, Cole, Pantoja and Razak attempt in the first instance to provide insight into the post-disaster destructions, as well as outlining the recovery, with the aim of ensuring the sustainability of the small economy in view of future challenges.

The explicit choice of Cole, Pantoja and Razak (1993) to describe the nature of economic processes in the immediate disaster aftermath and to simulate economic restructuring thereafter, led the authors to adopt the notion of an EAM, which is unique in the disaster community. The stage of structuring of chaos and disorder, basically

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[50] A somewhat similar approach, although referred to as a 'parameter matrix' approach in the extension of the so-called Indirect Loss module, can be found in HAZUS (FEMA, 2001, p.16-34). The HAZUS algorithm uses these matrices as a tool to make supply, demand and value added adjustments in the disaster aftermath sector-dependent. However, the particular construction of the matrix is not elaborated upon.

before recovery starts, is often overlooked by many authors. Only with accurate knowledge of the survived capacity and available resources in the disaster aftermath, can further recovery and reconstruction activities be planned and implemented. Cole, Pantoja and Razak (1993, p.B-8) attempt to find a solution for the disequilibrium stage via an 'event matrix'. They state:

> the intensity of an event E may be represented by changes in the coefficient matrix, say, E*A, and in the exogenous demand Y. This vector is related directly to the "event matrix" […] and simply measures the extent to which a particular activity has been disrupted. Hence, the total impact now may be written as:[51]
>
> $$X(T) = \{ I - E(T) * A \}^{-1} \; P(T)\, Y$$

Note, that an 'event matrix' may be a matrix or a vector, but should be compatible with the corresponding SAM (see also our description of the method in the previous Section). Also note that X, E and P (respectively, total output, changes in the production coefficients and cumulative impact) are functions of time. Time is an important parameter according to Cole, Pantoja and Razak, and has to be explicitly included in the analysis. Further on the same page, Cole, Pantoja and Razak (*ibid*) further clarify the meaning of an event matrix:

> In general, then, the "events matrix" is $E(w_{ij}, c_{ij}, t_{ij}, r_{ij})$. The parameter w_{ij} is the characteristic lag associated with the transaction […] The remaining parameters define the impact of the disaster and recovery – c, t and r respectively represent the initial impact, the time-scale for recovery, and the expected impact of reconstruction.

Apparently, the philosophy behind structuring the various steps in disaster analysis, like initial disruption and recovery activities through time, by means of an 'event matrix' is, irrefutably, an important methodological contribution to disaster modelling. Cole, Pantoja and Razak (1993, p.4-7) continue:

> In the most general case, the event matrix will be a set of tables corresponding to entries in the original input-output table which specifies i) the extent of damage to internal and external components, ii) the goal for recovery and iii) the time scale for recovery. The details [of how an event matrix is specified] will depend on the situation under investigation

However, the development of the matrices comprising the 'event matrix' received little further advancement in disaster studies. In particular, the precise mathematical definition and derivation of an EAM are missing, especially the connection between the E and A matrices. At the same time, Cole, Pantoja and Razak (*ibid*, p.3-16) themselves are proponents of the so-called 'expert system approach', which implies that, following the authors, matrices defining the initial distortion, as well as recovery are to be defined independently by outside experts in the field of economic recovery.

In our opinion, the definition of an 'event matrix', as stipulated above, offers another lead. We would like to distinguish two main stages here. Stage one encompasses element i), i.e. reflection on the real situation immediately after the disaster -primarily a listing of production and consumption imbalances- while stage two

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[51] We recognize here a variant of the Leontief or multiplier matrix to be discussed in Section 5.2. Here A is the matrix of input coefficients as appearing in equation [3.1].

consists of the elements ii) and iii), the direct recovery planning with implications for the long-run development trajectory. Moreover, in our view, the circle of disaster analysis as presented so far is not complete, as it is missing the proactive element, such as the analysis of prevention measures, the *ex ante* adaptation of an economy to the potential adversity, building up resilience and reducing vulnerability. For this purpose we suggest that a third stage has to be added to the proposed modelling activities, i.e. an evaluation of (policy) options that exist with respect to disaster preparedness. We shall return to this proposition in Chapter 6 when we introduce our own model. Before that, we have to discuss the arguments behind the choice of a basic modelling framework (next Section) and its construction (Chapter 5).

4.3.2. Choice of Modelling Framework

Models that we highlighted in this short review above, while each have their strong sides, seem to suffer from malfunction in some respect. Here, we summarise briefly the main points of limitation in current disaster effect modelling and make a choice of model for our own inference.

In our view, one of the features that disaster modelling has to reflect is that clarity and insight should be provided with respect to the immediate post-disaster situation. This is important because disaster studies, as we discuss them in this thesis, are considering a specific situation in which an economic system suddenly appears, which is a major calamity. This is in turn characterised by vast physical disruption, loss of lives and resources which consequently results in the loss of connectivity within the economic circular flow and a (possibly, enduring) imbalance situation, where the scale of the initial shock plays a leading role, as we discussed in Chapter 2 of this thesis. Modelling disaster repercussions in this way is becoming methodologically different from conventional marginal or step-wise impulse analyses, and should not omit the disequilibrium stage of disruption before proceeding to recovery exercises. This is probably one of the most widespread flaws, because modellers are ‘trapped’ within the merits of most existing models, based on the notion of equilibrium, which is in turn difficult to neglect. This implies essentially that care should be taken in choosing modelling tools for analysing disaster consequences and their appropriateness, while equilibrium models seldom appear to be adjusted to the specific purposes of disaster problem.

Further, some minor points should be addressed. Another problem is that other models lack a convincing geographical dimension or sometimes miss a connection to the spatial factor. Few models have explicit temporal boundaries, not always taking a wide range of economic effects present during the recovery phase into the analysis (which can also be positive alongside the negative repercussions of a disaster; for example, driven by the resilience potential). Next, some research efforts are directed at the scale of events, which is unusual, but not as grand as we define in this thesis. For example, very few works concerned a disaster such as Katrina, which points at the need for carrying out *ex-ante* large-scale analyses. Here, the problem is that we tend to draw inferences about future events based on previous occurrences; unfortunately, extremes sometimes do occur, and we need to be ahead of time and think about unlikely, though not impossible, events to prevent devastating catastrophes. Finally, some models are developed to suit particular (ad-hoc) needs, and therefore miss generality.

Nevertheless, by and large the methodological debate is still open, depending on what the country or region views as its biggest problem. One of the additional issues to be explored concerns policy in countries differing in political and economic structure, which also influences the choice of the model. In a pure market economy decisions made can be expected to differ from those made in a more regulated country. Here, we have to look for novel solutions which address the entire range of (pre)conditions. First of all we should decide on the choice of the level of analysis: at the moment, there is a need for a macro-oriented framework, which at the same time provides insight into the disturbance of structure and operation of the entire socio-economic system under the conditions of a calamity (Van der Veen, 2004). Next, modelling efforts should be oriented at providing a wide range of economic effects inflicted by a disaster, in particular covering the extent of direct and indirect economic losses throughout the system. Finally, it is essential that models are capable of covering available policy options. Whether proactive or recovery-oriented, policy measures should be modelled and analysed with regards to the possible response that these might cause throughout the economy. Being able to assess relative costs and benefits of various measures, such models would offer indispensable means to support decision-making.

After the review of literature on the existing models and discussion of their pros and cons, we may say that for the analysis of disaster consequences, we are looking for a model, which possesses three important features. Firstly, it is the ability to model a complex economic system, where numerous actors are interdependent on each other, producing high-order interconnectedness. Secondly, it is the capability to model a system which is (temporarily) out of equilibrium and tends to return to a (new) balance. Thirdly, the model should include a module to treat the analysis of policy options anticipating and preparing for a calamity. The combination of these three conditions for a model is a truly challenging task.

Which model should be chosen to analyse a complex disrupted economic system? What limitation and opportunities, both available at present, as well as still unexplored, do models offer for disaster analysis? These questions are not easy to answer; there basically are just too many unknowns. We addressed this issue in Chapter 3, where we stated that, depending on the kind of questions we wish to address, different models are used for economic analysis of major catastrophes. Certain preferences seem to exist, depending on country and type of catastrophe we wish to study. In the United States, for example, a number of *market-based approaches* have been presented recently focusing on short and medium run disequilibria (see, for example, Cole, Pantoja and Razak, 1993; Cochrane, 1997a,b; Rose and Lim, 2002; Cole, 2003; Okuyama, 2004; Okuyama and Chang 2004; Okuyama, Hewings and Sonis, 2004). Yet, not many authors have considered economies, where government exercises relatively significant influence on the markets, where modelling would require more attention to the (proactive) policy side (we shall return to the discussion of the role of government in water management and flood policy in the Netherlands in Chapter 8).

Other existing analytical frameworks circulating internationally contain Computable General Equilibrium and Input-Output models, including their Linear Programming variants, and social accounting matrices. All have their strong and weak points. Input-Output models offer a transparent structure of an economy by sector, allow concentrating specifically on the physical side of the problem at hand, and are temptingly simple. And although input-output is widely used as a methodology for dealing with large-scale disruptions we are discussing, it still needs methodological fine-tuning for the maturity required for this type of analysis. In fact, standard Input-

Output methodology, stressing interaction and equilibrium, does not offer a very flexible set of tools to deal with post-disaster situations characterised by persistent disruption and disequilibrium. This problem is partially shared with the CGE methodology, which is often seen as a superior alternative to input-output approaches.[52] In a sense it can be argued that standard Input-Output, being limited by the fixed production functions (essentially, proportions between the inputs used, which are technologically determined), is an antipode of the CGE models deemed to be intricate, involving multiple actors and markets, and flexible, allowing markets to adjust elastically through the price mechanism to the new circumstances. Rose (1995, p.296) holds an opinion, which can bridge the gap in the methodological debate between CGE and I-O proponents:

> "…economists using CGE models often see them as clear improvements over I-O. They point to an enhanced emphasis on institutions and a broader set of interactions, or to non-linearities and substitution possibilities in response to market signals. At the same time, they often fail to acknowledge that their models are based on more restrictive assumptions than I-O models, in that they typically assume optimizing behavior and that the economy is in equilibrium. Most important is the fact that these more recent multisector formulations would be of limited value without an I-O model of sectoral interdependency as part of their theoretical core and without an empirical I-O table to make them operational."

Also, while acknowledging the value of CGE and its merits, it is not exactly what it seems, in the light of calamity analysis. Although CGE models can be exceptionally suitable for the analysis of impacts in terms of price-quantity adjustments, this often used framework should be applied with due care to the analysis of disaster consequences. We shall briefly address this in conjunction with disaster analysis. Firstly, CGE as an equilibrium-oriented model requires a system to be in balance, while disturbance caused by a calamity can require a substantial recovery time before a (new) equilibrium is found. This means that the model in its standard formulation cannot handle modelling such circumstances. Next, the flexibility allowed by CGE concerning price adjustments to quantity restrictions may not always be applicable in a calamity. Because a substantial part of the productive capacity is gone, the catastrophe can be expected to cause a great deal of *imbalances* or *disproportions* in the economy's supply-demand relations. It can endorse persistent situations of shortages of some products as well as over-proportional supplies of others, which can substantially expand the duration of the recovery period for an economy. In addition, when discussing the concepts of disaster, damage, and resilience (Chapters 2 and 3), the sheer scale of the disaster becomes a separate factor in itself. Then, as we pointed out, rigidities may play a significant role. Sometimes the markets are not allowed to clear because of government interference and imposition of price ceilings, free emergency aid or rationing of a wide range of products. Other restrictions for working of the market mechanisms can be caused by the chaos in the economy immediately after a major calamity, unavailability and imprecision of information, lacking means of payment, *et cetera*. Also, in places where some areas are hardly reachable, and where markets can essentially become strongly localised and disconnected, coming back to normal is a

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[52] For example, Rose Oladosu and Liao (2007) distinguish five types of disequilibrium in their modeling: disequilibrium in the labour market through the Keynesian Closure Rule; disequilibrium in the trade markets through trade imbalances; disequilibria in the government accounts through deficit spending; disequilibria in goods markets through shortages of critical materials; and disequilibria through price rigidities.

challenge. Rose and Guha (2004, p.137), supporting this, state the following: "the typical CGE model, even based on short-run (vs. long-run) substitution elasticities, is far too flexible and is likely to greatly understate earthquake impacts […] Deliberate efforts must be made to incorporate real world rigidities as well as resiliencies." We may infer from this that the authors, essentially, suggest that CGE framework used for major shock analysis, with its underlying assumptions of substitutability and (instantaneous) price adjustments, exaggerates the real abilities of economic systems to react and adapt in the face of disturbance, which would lead to overly optimistic estimations of disaster impacts in general. We should add that, in our view, rigidities and proportions should get a more prominent role in modelling disaster aftermath in modern economies.

In choosing an appropriate approach, thus, one is confronted with trade-offs between the extent of the complexity and flexibility that the models are able to offer in situations where an economy is facing an entirely new set of circumstances. Here, decisions have to be taken in a non-standard way in the light of suddenly restricted or unavailable resources and disrupted connections within a system. Therefore, in our inquiry of the fundamental issues underlying a disaster event, our choice of a modelling framework is stipulated by the questions we want to answer. Namely, in light of the nature of a large-scale calamity, the specificity of the shock to be analysed, and the methodological challenge we are facing, we suggest that the Input-Output model, as a basic tool for inquiry, can be a suitable candidate for a framework. We believe that it possesses a lot of potential, worthwhile to explore. Input-output is unique in the sense that, it is one of the first models of sufficient range and usability to analyse issues such as policy change, technological change, international trade and natural resources (see Rose, 1995). There are a number of advantages that we see connected to the decision to take input-output as a basic framework. First of all, we are attempting to gain an overview of an entire economic network. Second, the recognised strength of the framework is its simplicity and transparency, which, in combination with the covered interconnectedness of an economy, gives a powerful argument in its favour.

The insight provided by the input-output is nowadays also widely used and further developed by researchers and planners in such countries as the US and Japan, as well as in developing countries, where the neutrality of its formulation is preferred (Rose, 1995). The issue of neutrality of model formulation can be interpreted in terms of modelling reconstruction programmes in the calamity aftermath, and whether these should be regulated and steered by the government or whether market-based solutions are preferred for the economy to restore its equilibrium. In fact every economy consists of a mixture of private and public sectors, which means that not all markets can be cleared automatically with the help of an 'invisible hand'. This implies that government interference in case of emergency may be necessary; however, the degree of this involvement is a major point for discussion. Whereas American scholars, from a country where markets are more prominent, tend to opt for market-oriented solutions (and where CGE models are perhaps more appropriate), European scientists, where governments play a more significant role in the economies, tend to pay more attention to regulatory approaches. In the latter case, the choice of policy formulation, as offered by input-output, may be considered an advantage.

Another strength of the Input-Output model is its excellent link to the empirical realm; data in the form of input-output tables are regularly collected and organised: this is one of the richest statistical databases in many countries around the world. Input-Output allows for the concentration on different industrial as well as regional aggregation levels and the studying of various effects, from local to global. Though in its standard formulation using input-output cannot satisfy the needs of the new type of economic disaster consequence analysis, its potential means that we can stretch the borders beyond conventional analysis and look for alternative solutions. In fact, one of the input-output fundamentals, which fits our needs to describe the 'real' economy, is its connection to the physical world, which we have to reflect on, with its disruptions and malfunctions, before taking on the commitment to model possible recovery trajectories.

In this respect, we propose a more general position on modelling major disruptions in economic networks based on the Input-Output framework. Here, a procedure is necessary based on the division between the immediate disaster aftermath, the recovery planning and the analysis of possible precautionary measures. We hope that this generalised approach provides a connecting bridge between the theoretical foundation of the model and its empirical application for disaster analysis. We suggest returning to input-output fundamentals, trying to give more flexibility to what basically appears a rather rigid framework. We shall conclude this Chapter with a short summary, and continue with the description of an input-output framework in Chapter 5.

4.4. SUMMARY AND DISCUSSION

In this Chapter we discussed methods and models now being used in disaster consequence analysis for modern economies. We were particularly interested in the discussion of the methodologies for the study of economic inferences connected to major calamities. In this Chapter, we offered a selection of authors contributing to the field with studies on the economic impacts of disasters on contemporary societies. We signalled a missing convergence in the scientific disaster community concerning methodological issues of disaster analysis. This may delay the development of more integrated methods, for which we wish to plea.

We divided the discussion of the literature in two parts, i.e. Dutch modelling exercises and international expertise. The reason is that the danger of floods in the Netherlands as a low-lying country triggered the need to conduct broad flood damage assessments. Historically, much knowledge was accumulated within the scope of physical damage evaluation and prediction, as the field was dominated by civil engineering advances and expertise. However, until recently, little was known about the economic repercussions of a major flooding of the country. Probably the first effort to arrive at an integrated assessment of damage was the so-called 'standard method' (Vrisou van Eck, Kok and Vrouwenvelder, 1999; and Vrisou van Eck and Kok, 2001), which was recently upgraded in one of the government reports "Flood Risks in the Netherlands" (see MTP, 2005b). However, the method does not have a profound indirect loss estimation module, and it presumably involves the double counting of losses. Two later reports from NEI and Tebodin (Briene *et al.*, 2003; Van den Berg *et al.*, 2000) include a better description of the indirect effects of a potential flooding, which is estimated based on the input-output multipliers, adjusted for substitution effects between and within the sectors. Furthermore, Eijgenraam (2005) suggests a model to support economic decision-making for the problem of investing in protective dike improvements. Here, the author takes into account the amount of direct and indirect effects of potential flooding, to provide the optimal level of protection, but the economic damage is borrowed from HIS, which is in turn based on the standard method.

All these works are characterised by micro- and meso-approaches, based on the calculations per dike ring.

On the meso-macro level, the team of the Erasmus University of Rotterdam (Van Ast, Bouma and Francois, 2004) has developed what they refer to as the risk assessment approach, where attention is paid to the methodological side of the problem. Furthermore, the work of the Twente group resulted in a number of project reports and publications. Van der Veen *et al.* (2001) instigated the discussion on the societal and economic effects of large-scale calamities on the national level, stressing the importance of a theoretically sound approach. Delft Cluster reports then followed (Van der Veen and Logtmeijer, 2003; Van der Veen *et al.*, 2003a,b), explicitly focusing on indirect economic damage methodology and mapping of important economic activities. Later, the methodological developments in the disaster analysis of disruption, recovery and policy were continued, offering the building blocks for a three-step procedure within an input-output framework (Bočkarjova, Steenge and Van der Veen, 2004b). Inferences in the economic hotspot determination and mapping can be found in Van der Veen and Logtmeijer (2005). However, the debate on the approach most suited to the Dutch situation and flooding disasters is open and further advances are being made.

In the international arena, the topic of a methodology dealing with economic disaster consequence estimation remains a continuous subject for scientific debate. The international and national bodies involved in disaster protection and preparedness are sometimes the same ones providing broad guidelines or frameworks for broad damage estimation, although they rarely offer a model (see, for example, MAFF, 1999; BTRE, 2001; ECLAC, 2003; Benson and Clay, 2004). Macro-models offered by IIASA (Freeman *et al.*, 2004; Mechler, 2004 and 2006; Linnerooth-Bayer, Mechler and Pflug, 2005) are much more tangible and usable. However, these mostly deal with macro-effects and risk financing in and for developing countries, which provides a different focus than the one we are studying in this thesis.

Typically, in disaster economic modelling among academic scholars, one can see that opinions are divided on the use of models, which often leads to the discussion of the Input-Output approach *vs*. the CGE approach. Rose and colleagues, however, use both frameworks and offer extensive methodological accounts. For example, Rose and Benavides (1998) and Rose and Liao (2005) provide an input-output analysis of a lifeline breakdown and its effects on the disruption of production activities. At the same time, Rose (1995, 2004b), and Rose and Lim (2002) provide methodological insight into economic disaster modelling and challenges associated with this. Furthermore, Rose (2004a, 2006), Rose and Liao (2005) choose to concentrate on the issue of economic resilience in a disaster context and its quantification with the help of CGE modelling. Ultimately, Rose offers a legitimate claim that essentially disaster analysis is different from the ‘usual’ modelling based on equilibrium and a smaller scale of changes. In turn, for disaster modelling, regular models need to be adjusted to particular major shock requirements.

In our overview of the literature on disaster modelling we note that there is a whole range of authors who favour the input-output approaches as a leading modelling framework. Apparently, input-output models offer a rich potential for disaster analysis, not all of which, however, has as yet been discovered. In this Chapter we illuminated a number of input-output based models for disaster analysis. The approach of Cochrane (1997a,b and 2004) and HAZUS (FEMA, 2001) are based on manipulating an input-output table to account for disaster losses, after which balancing takes place by adjusting inventories, imports, exports and existing substitution capacity within sectors to take over part of the lost production. Although this is an attractive module, the approach seems to be less transparent and is in a sense ad-hoc, where the opportunities for rebalancing are determined by the user. Cole and colleagues (Cole, 1998, 2004b; Cole, Pantoja and Razak, 1993) offer several works based on the input-output approach and SAMs, presenting the possibilities for analysis, by means of what they call an event accounting matrix, the EAM. The EAM, an innovative element that captures the essence of post-disaster disorder and later recovery planning, is a concept which has not yet reached its definitive shape, but which is an excellent departure point for further research. In his later studies, (Cole, 2003, 2004a) extends his modelling to an insurance accounting matrix approach, introducing protection investments as a 'buffer' for an economy to be used when disaster strikes.

Furthermore, Santos and Haimes (2004) offer the so-called inoperability input-output model for analysing the repercussions of a terrorist attack, although they do not include disequilibrium modelling. Finally, Okuyama, (2004) and Okuyama, Hewings and Sonis (2004) provide a time-adjusted input-output based sequential interindustry model, the SIM. The advancement of the model into the analysis of production chronology and recovery planning are worth noting, but the disequilibrium stage remains a problem.

After analysing the models at hand, we finally returned to the discussion of our goal of choosing the framework to be used, as a basis for the adjustments to achieve the prototype of a disaster model. Ultimately, to do so we need a novel way of looking at the established modelling framework. As in the literature we reviewed, the main line of the debate concentrated on the two major models used in the field, i.e. the I-O and CGE approaches. The decisive confrontation of the two frameworks made us realise that CGE, with its range of valuable features, such as behavioural equations and attention to detail in the high-level analysis, as well as a great deal of flexibility, still remains unsatisfactory. As noticed by a number of researchers in disaster analysis, CGE loss estimates are often understating real losses, because they rely on a high degree of substitutability. This means, that more account should be given to post-calamity rigidities. Also, we think it is important to model disequilibrium first, before proceeding with recovery and reconstruction analysis. At the same time, input-output, with its transparency and simplicity in reflecting the complex relationships within an economic network, fits better to our needs of a basic modelling framework, able to provide answers to fundamental questions in disaster analysis. With its range of possibilities and neutrality of formulation, input-output offers a promising territory to be explored and exploited for the requirements of gaining inference in disaster phenomenon.

Along the way, we established the importance of the meso-level, addressed by input-output types of model. It focuses on the interactions at this level, and has excellent potential also to address disruptions in these interactions. Simultaneously, we already touched upon the presence of certain rigidities, both of a technological and an institutional nature. These rigidities show up in certain model parameter configurations that are less flexible than others. These, later on, will be reflected in our views on disaster modelling.

In the next Chapter we shall describe input-output in its standard formulation, and then proceed to the construction of our adjusted approach to model disaster consequences in Chapter 6. We shall start with its fundamentals and provide the necessary extensions to the model to shape it as a disaster analysis tool.

Chapter 5

Input-Output Methodology

5.1. INTRODUCTION

So far we have addressed conceptual issues in the field of disaster analysis. We introduced the topic of disasters in modern societies and their economic consequences, discussed the fundamental concepts frequently used in this type of analysis, and reviewed the literature, highlighting selected works with the focus on gaining insight into the processes in an economic system, which appears to be under pressure when a disastrous event occurs.

In the preceding Chapters, we prepared the stage for our methodological inference in modelling, and, in particular, selecting and building a model for the specific needs of a major shock analysis. We have based our insight into the nature of disaster on the idea of the circular flow in an economy. A number of features distinguish our approach, where disequilibrium and loss of connectivity play the main part. For the analysis of economic disaster consequences in modern industrialised economies, we selected the input-output framework (see the discussion of the literature in Chapter 4) as a basic point of departure for constructing our own modelling instrument. The transparency of an input-output framework and its rich potential to disclose relationships within an economic network of circular flows were the central features which determined our choice.

Input-output analysis is a method of systematically quantifying the interrelationships between the various sectors of a complex economic system based on the notion of technology. It is a recognised tool to reflect the circularity of flows within an economy, which is central to our inquiry. Operationalisation is usually in terms of transactions between the constituent parties, such as business enterprises, consumers or consumer groups, public authorities and parties or agents abroad. These transactions are grouped into those dealing with the basic elements of an economy, such as (types of) production, distribution, transportation, consumption, *et cetera*. The interactions are represented as the entries in a square or rectangular matrix. The *rows* of the matrix register the sales of each production sector to other sectors or to consumers of the final product. The *columns* tell us about the purchases of each sector from other sectors or from the providers of the so-called primary inputs. Each number in a row is simultaneously a number in a column; each output is also an input into some production process. The double-entry bookkeeping of the input-output table reveals the fabrics of an economy, connected by the flows of trade, ultimately linking each sector of the economy to all the others.

An input-output table is constructed from the observed data for a particular geographically well-defined economic area. In practise, the economic system to which it is applied can be as large as a national or even the global economy, or as small as the economy of a metropolitan area or a single enterprise. The economic activity in this area consists of a number of segments or producing sectors. These can be industries in the usual sense, i.e., sectors of an economy according to a recognised classification scheme (like the international Standard Industry Classification, SIC), or even much smaller categories. The level of detail (or, vice versa, of aggregation) can vary according to the opportunities that the data allow or the requirements of the goals set. Experience has shown that work on input-output matrices construction involves ongoing discussions on the basic problems of classification, definition and treatment.

The input-output model can be used for simulating the consequences of various forms of economic policy. Some models involve special types of economic control or optimisation. Many applications involve scenario analysis, running or testing the model under different assumptions regarding instruments considered relevant to the policy issues under discussion. The instrumental approach (Tinbergen , 1952, 1956) consists of specifying the targets (e.g. concerning the balance of payments, sectoral or regional employment, and so on) and then determining how to fine-tune the set of policy instruments to reach the targets. This involves the complicated task of establishing the time path (including lags) between the introduction of the instrument and its effect on the target.

After the short introduction in Chapter 3, in this Chapter, we shall provide a further description of the standard input-output framework. We believe that in order to answer the fundamental questions in disaster analysis guarding our research, we should start from the basic elements underlying the construction of an input-output model, namely, the physical side of the model, its embodied interpretation of the real world, and its ‘accounting’ background. This has also been Leontief’s approach to model economies and to provide forecasts – building his conclusions on his view of economic theory, yet with a eye on the real events and processes taking place in the economy (Bederov and Kapkov, 2003). We shall conclude this Chapter by discussing the restrictions and challenges of the model in the light of our intended analysis, and by preparing the groundwork for the construction, and in essence, the extension, of the basic model in the next Chapter.

5.2. DESCRIPTION OF AN ECONOMIC STRUCTURE: THE INPUT-OUTPUT MODEL

5.2.1. Some Background

Input-Output has a long history. Its origin dates back to the Eighteenth century French authors, in particular the Physiocrats, who developed an early form of an input-output table, the so-called *Tableau économique*. This Tableau was based on the concept of circularity, the notion suggesting that social and economic systems can be described in terms of an uninterrupted and interconnected flow of goods and services from producer to consumer, and back. Disruptions of the circular flow means that shortages arise or that production will be in excess of demands, with detrimental consequences for the economy. Later, many authors worked on various forms of input-output theory. We can mention the names of Marx, Walras, Cassel, Popov, Wald, and Von Neumann. However, in particular the Russian-American scholar Wassily Leontief provided an appropriate framework for empirical applications of input-output theory. During the 1930s he published input-output tables for the American economy, which he interpreted as modern Tableaux économiques. Besides being a description of the economy, the main purpose was to investigate the impact of shifts in final (consumer and investment) demand and technological change on the American economy. The focus was in particular on the consequences of such change on major variables such as employment, import-export balances, and the price level. During the 1940s and 1950s, input-output became the core of modern national accounting, due to the work of scholars as Stone (1962), and others.

In 1953, Leontief presented a dynamic version of the basic model (Leontief, 1953). He accomplished this by modelling investments in production capacity along input-output lines. This meant that a new matrix, the so-called capital matrix, was incorporated in the model. The i^{th} row of this new matrix represented the sales of industry i to the other sectors for enlarging productive capacity. The i^{th} column, just as in the input-output matrix, registered the purchases of industry i needed for its capacity enlargement. Leontief's approach led to a number of developments. First of all, it provided a basis for multi-sectoral work in growth and development economics. Furthermore, it was a significant stimulus for theoretical work on the mathematical properties of dynamic models. It also meant a new starting point for academic and national accounting work on the construction of empirical capital coefficients matrices.

Regional applications of input-output analysis date back to the early 1950s (Isard, 1951; Chenery, 1953; Moses, 1955). Later, after substantive standardisation, extensions into inter- and intra-regional analysis became available, as did applications in the supra-national field for international comparison (Polenske, 1980). Further developments of the input-output model included the introduction of social accounting matrices (SAMs) in which the social and cultural aspects of economic change were recorded (we could find this approach in our literature review, namely, Cole, Pantoja and Razak, 1993; Cole, 1995 and 2004a,b). The new United Nations' System of National accounts (UN, 1968) was a revision and an update of the existing system of national accounts. Initially there were two variants of the model: quantity and price versions. At present there is a large body of literature on input-output theory and application, see e.g. Kurz, Dietzenbacher, and Lager (1998). The mathematical foundations were substantially developed over the years. At present, each input-output model basically consists of two forms. There is the primal or real model, which gives us the relations in the real sphere. The dual or price model gives the price implications. Extensions are now available in several areas. These include: Extensions of the basic model to deal with environmental pollution policies; Applications of input-output techniques to the structuring of demographic and social data, which were at the basis of the rise of socio-demographic models; Application of programming methods to data processing and model construction and solution.

5.2.2. The Basic Model

The basic unit of the table is the transaction between its constituent parties (firms, sectors, industries, consumers, governmental agencies, and so on). The set of transactions consists of two parts, intermediate and final deliveries, where all entries are in value (money) terms. If a delivery is intermediate, it means that it is an input in some (other) production process and, hence, is processed further. A delivery is final if it is bought without any intention of further processing. Let us consider now the intermediate purchases of a sector *j* (i.e. the sales of all sectors to this sector *j*). As mentioned, in input-output analysis a column vector is used to represent these purchases. The elements of this vector then register both the origin and the magnitudes of sector's *j* inputs. If we denote the observed (monetary) value of the flow from sector *i* to sector *j* by the symbol z_{ij}, we get the (column) vector:

$$\begin{bmatrix} z_{1j} \\ \vdots \\ z_{ij} \\ \vdots \\ z_{nj} \end{bmatrix} \qquad [5.1]$$

Returning to the input-output table, the rows of the z_{ij}'s record where the *intermediate* output of each sector end up. If there is no separately distinguished final demand, total output (x_i) can be written as:

$$x_i = z_{i1} + z_{i2} + ... + z_{ij} + ... z_{in} \qquad [5.2]$$

The set of all linear equations expressing the balances for each commodity being produced or used in the course of one (static version of the model) or several periods of time (dynamic version) completely describes the interdependence among the sectors of the given economy. Sector *j*'s demand for inputs from the other sectors during the year in this way will be related to the amount of goods produced by the same sector *j* over the same period. Applying this to the *n* sectors we obtain the mathematical structure of an input-output system, see Table 5.1 below.

The fundamental law of input-output 'accounting' equilibrium ensures that the corresponding row and columns totals of an input-output table must be equal. That is, the following equality should hold:

$$\sum_{i=1...n} z_{ik} = \sum_{j=1...n} z_{kj} \qquad [5.3]$$

		Purchasing sector					**Total**
	Sectors	*1*	…	*k*	…	*n*	
Selling sector	*1*	z_{11}		z_{1k}		z_{1n}	$x_1 = \sum_{j=1\ldots n} z_{1j}$
	…	…	⋱	…		…	…
	k	z_{k1}		z_{kk}		z_{kn}	$x_k = \sum_{j=1\ldots n} z_{kj}$
	…	…		…	⋱	…	…
	n	z_{n1}		z_{nk}		z_{nn}	$x_n = \sum_{j=1\ldots n} z_{nj}$
	Total	$\sum_{i=1\ldots n} z_{i1}$	…	$\sum_{i=1\ldots n} z_{ik}$	…	$\sum_{i=1\ldots n} z_{in}$	$x = \sum_{j=1\ldots n}^{i=1\ldots n} z_{ij}$

***Table 5.1** General form of an input-output table*

This logically leads to another equality, stating that the sums of all columns should equal the sums of all rows:

$$\sum_{j=1\ldots n}^{i=1\ldots n} z_{ij} = \sum_{k=1\ldots n} \sum_{i=1\ldots n} z_{ik} = \sum_{k=1\ldots n} \sum_{j=1\ldots n} z_{kj} \qquad [5.4]$$

The input-output transactions matrix in absolute terms (as above) can also be transformed into a matrix, which entries are expressed in terms of production (or technical) coefficients. If we denote technical coefficients as *a*'s, these are obtained by dividing the entry in each cell in monetary terms by the total sum of the respective column:

$$a_{ij} = \frac{z_{ij}}{\sum_{j=1\ldots n}^{i=1\ldots n} z_{ij}} = \frac{z_{ij}}{x_j} \qquad [5.5]$$

A matrix, which contains a_{ij}'s as its entries is conventionally denoted as **A** matrix and has dimension (n x n). This matrix is referred to as the matrix of technical input-output coefficients, and accordingly represents the technical structure of the whole economic system. Thus, production coefficients show in the essence the production technology visible by columns, determined by the structure of purchases of each sector, which are in turn used as production inputs. On the other hand, row-wise we observe the sales structure of each industry as the row entries reveal sales of each sector's products to other sectors. The transition from the coefficient form of the transactions matrix for its typical element a_{ij} is simple, and can be directly derived from the equation [5.5] as $z_{ij} = a_{ij} x_j$.

In addition to the intermediate deliveries, we distinguish sales to purchasers whose decisions are external (or exogenous) to the (decisions of the) industrial (i.e. producing) sectors - for example, households, governmental agencies and foreign trade. The demands of these units – and hence the size of their purchases from the industrial sectors – are generally the outcome of considerations outside the domain of the producing units. Therefore, the demand of these external units is generally referred to as a final demand, basically being exogenously given. Denoting by f_i the final demand for sector's *i* production, we can add it to the existing intermediary output on the right hand side of equation [5.2] and obtain the total or gross output for sector *i*:

$$x_i = z_{i1} + z_{i2} + \ldots + z_{ij} + \ldots z_{in} + f_i \qquad [5.6]$$

We can now substitute the z_{ij}'s for the above derived production coefficients a_{ij}'s in equation [5.5]. This results in an expression for the total outputs in matrix notation, which is the basic relation of input-output analysis:

$$x_i = \sum_{j-1 \ldots n} a_{ij} x_j \;+\; f_i \qquad \forall i \qquad [5.7]$$

or, in the notation of Chapter 3:

$$\mathbf{x} = \mathbf{Ax} + \mathbf{f} \qquad [3.1]$$

where **x** and **f**, respectively, stand for the vectors of total output and final demand, and **A** for the matrix of input coefficients, all in the initial situation, before the shock. We distinguish n industries, so **A** is (*n* x *n*), while **x** and **f** are (*n* x 1). Also, we should note that the final demand category is usually subdivided into several categories, such as domestic final demand and foreign final demand. Domestic final demand again may consist of vectors of household consumption (C), government expenditures (G), investments (I) and other elements; foreign final demand is referred to as exports (E). Thus, total output in an economy adds up to the well-known equation:

$$x_i = z_{ij} + c_i + g_i + i_i + e_i, \qquad [5.8]$$

where c_i, g_i, i_i and e_i are the column elements, respectively, of private consumption, government expenditures, investments and exports, which are also found in Table 5.2. Alternatively, being engaged in a production process, each sector not only has to pay for the inputs it obtains from all other sectors (including itself), but also has to pay for other types of inputs, such as labour (W) and capital (N). Together with certain other categories, such as imports (M), these form the 'value-added' part (V) of sector *j*. These items together are known as the 'payments' sector or primary cost categories. Incorporating them into a formula for total expenditures, we obtain:

$$x_j = z_{ij} + w_j + n_j + m_j \qquad [5.9]$$

where, correspondingly, w_j, n_j and m_j represent the row elements of the primary factors, respectively, wages, capital and imports. We now can express the whole system in the following way as appears on Table 5.2 below:

		Processing sectors (purchases)	Final demand				Total output
		1 … j … n					
Processing sectors (sales)	1 … i … n	**Z**	c_i	g_i	i_i	e_i	x_i
Payments sector	Value added	w_j	0				W
		n_j					N
	Imports	m_j					M
Total outlays		x_j	C	G	I	E	X

Table 5.2. *Expanded flow input-output table*

So, let us elaborate some more on the formulas [3.1] and [5.7]. We can straightforwardly transform to have **x** as a function of **f**. We obtain:

$$(\mathbf{I}-\mathbf{A})\mathbf{x}=\mathbf{f} \qquad [5.10]$$

or,

$$\mathbf{x}=(\mathbf{I}-\mathbf{A})^{-1}\mathbf{f} \qquad [5.11]$$

where matrix $(\mathbf{I}-\mathbf{A})^{-1}$ is usually referred to as the Leontief inverse, or the multiplier matrix. Denoting its elements by the symbol α_{ij}, we thus can write the equations [5.5.] and [5.6.] as:

$$x_i=\alpha_{i1}f_1+\alpha_{i2}f_2+...+\alpha_{ij}f_j+...+\alpha_{in}f_n \qquad [5.12]$$

This shows in a direct way the dependence of gross output on the f_i's. In fact, looking at the α_{ij}'s in this context, we notice that we have $\alpha_{ij}=\partial x_i/\partial f_j$. Verbally, the α_{ij}'s (or multipliers) represent the amount by which gross output would change given a unit change in final demand. This property can be utilised to obtain a simple model:

$$\Delta\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1} \Delta\mathbf{f} \qquad [5.13]$$

In general, the multipliers of the famous $(\mathbf{I} - \mathbf{A})^{-1}$ Leontief inverse account for the total effect of the exogenous impact (which is initiated by the change in final demand as discussed above).[53]

It is also possible to find multiplier $\alpha_{\cdot j}$ for each sector *j*. In a general mathematical formula, this sectoral multiplier can be presented as a sum of all multipliers in the respective column *j*:

$$\alpha_{\cdot j} = \sum_{i=1}^{n} \alpha_{ij} \qquad [5.14]$$

This sectoral multiplier can be used to see what the first-order and second-order sectoral effects are of an exogenous shift in final demand. The first-order effect of changed final demand for the product of sector *j* ($\alpha_{\cdot j}$) represents in this context the increase of its demand for inputs to increase its output by the amount of the expanded demand for its products. The second-order effects ($\alpha_{\cdot k}$) reflect the responses of other industries (as well as sector *j* itself, and thus it incorporates both inter-industry and intra-industry connections) to the increased final demand of sector *j*. The reason is that all other sectors will have to produce more of their products to supply sector *j* with the inputs necessary to produce the extra goods or services needed for the increased final consumption.

As an aside, first- and second-order effects as described above cannot be directly translated to or compared with the direct and indirect effects that we defined in Chapter 3. The reason is that as a result of a major disturbance (such as a disaster), part of production capacity, alongside the part of the final demand, is gone; thus, the system itself has shrunk. In this sense, a direct effect would include both exogenous changes of lost demand and lost production capacities; indirect effects would be determined as a reaction to that exogenous shock within the system. Here, multiplier effects will be interpreted as indirect effects. Yet, the really important question to answer is whether multiplier analysis is appropriate is such a situation, or that alternative ways of exploring system's response should be explored. We shall come back to this issue in Chapters 6 and 7.

To complete the model, we will add the labour market. We recall that we already have paid attention to labour as a special factor of production in the beginning of this Chapter. One reason we mentioned is that labour market effects play an essential role in disaster analysis, because disturbances in this markets are a prime origin of long-term delays in recovery and growth. Labour also is that part of the value-added rows of an input-output model that probably is most directly involved in the production processes. It is purely technologically determined, which is somewhat different in the case of all

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[53] In the literature devoted to input-output modelling the type of multipliers just described is being referred to as *simple* multipliers. These are distinguished from *total* multipliers, which are found via elements of the Leontief inverse of a model that is closed with respect to households. In this thesis only *simple* multipliers are considered following this notation computed for the open model (Miller and Blair, 1985, p.102).

other categories. Depreciation and imports have different backgrounds being a) much more institutionally determined, and b) being more flexible in terms of the presence of substitutes. The other elements of the value-added rows, such as taxes and subsidies, are purely exogenously determined.[54] For ease of exposition we shall treat labour as the single primary input factor in the production function. In the standard input-output formulation we then have:

$$L = \mathbf{lx} \qquad [3.2]$$

where **l** represents the vector of direct labour input coefficients and the scalar L total labour income. We shall follow, as mentioned, standard input-output methodology in imposing that the relation between **A** and **l** is technologically determined. In addition, we impose that all entries are in money values. This is most useful since money value representations increase the direct comparability across sectors, regions or time intervals.[55] We thus work with physical units expressed in particular monetary terms; see Miller and Blair (1985, Ch.2). We also need a price equation. With equilibrium prices **p** and a wage rate *w*, standard we have:[56]

$$\mathbf{p} = \mathbf{pA} + w\mathbf{l} \qquad [3.3]$$

We already mentioned the implied income equation:

$$w\mathbf{l}\,\mathbf{x} = \mathbf{p}\,\mathbf{f} \qquad [3.4]$$

We also notice that the economy described by the above equations is in perfect internal balance. In fact, we meet here a perfect circular flow in the sense that commodities are simultaneously inputs and outputs of each production process, either directly or indirectly. Corresponding row and column sums are equal, reflecting the equality of supply and demand at the sectoral level. This also is valid for the labour equation: the wages that are paid by the employers is spent on goods and services as represented in the commodity bundle **f**.

5.3. A DIGRESSION INTO DYNAMIC INPUT-OUTPUT MODELS

Scenario analysis is one of the strategies to explore long-run economic behaviour, where the term ’long-run‘ often is taken to imply that changes in technology may be part of the analysis. Another aspect is provided by changes in output volume. If capacity

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[54] Imports, on the other side, form an even more complicated post of the value added part, as it includes goods that are produced by other types of sector. One may see imports thus as a component that reflects the exceeding capacity of in-home industry, as sectors have to import those inputs that are not available on the domestic market, or which home producers are not able to produce in the necessary amounts.

[55] We should recall that the total national product expressed in money terms is often taken as a proxy for national welfare.

[56] In the case of money values, we encounter the alternative notation **e** = **eA** + **l**, where each element of **e** is equal to unity, and the wage rate fixed at unity.

constraints may form a problem, changes in output will have to be accompanied by expansion of the production volume. This usually means that the economy is confronted with the necessity of a substantial investment in capital goods. (We should note that investment aimed at expansion should be distinguished from replacement investment, which does not increase capacity). Modelling investment, however, asks for the introduction of a time dimension into the model. Leontief (1953) was the first scholar to explore an extension of the basic form [3.1] along this line. To this end, he introduced a so-called capital matrix **B**. The element b_{ij} of this matrix stands for the amount of capital stock of good *i* necessary to produce one unit of good *j*.

The introduction of the necessity to produce capital goods meant that this type of production, previously a part of final demand f, now had to be accounted for explicitly. Below, we shall first briefly refer to Leontief's original model. Hereafter we shall, also briefly, discuss the Duchin-Szyld model (1985), which addresses a number of shortcomings of Leontief's original model. Leontief started with a closed form, given below. That is, there is no separate entry yet for exogenous final demand.[57] We have, for a single time period:

$$\mathbf{x}_t = \mathbf{A}\,\mathbf{x}_t + \mathbf{B}(\mathbf{x}_{t+1} - \mathbf{x}_t) \qquad [5.15]$$

or,

$$\mathbf{x}_t = [\mathbf{I} - \mathbf{A}]^{-1}\,\mathbf{B}(\mathbf{x}_{t+1} - \mathbf{x}_t) \qquad [5.16]$$

where we immediately recognize that [5.16] is an extension of [5.11]. Solving for $\mathbf{x}_{t+1}$, we find that future paths can be expressed in terms of properties of matrices A and B, their interaction, and the initial position of the economy. We also see that this model offers a most interesting approach to the stock-flow discussion presented earlier. Part of the total production $\mathbf{x}_t$ is flow, and is used up during one period. Another part of production (**B**) crystallises into stock magnitude and adds to capacity. The model offers a consistent way of dealing with these two dimensions.

The above model, however, has a number of shortcomings in terms of stability issues. These are caused to a large extent by the specifics of the accelerator part (such as a requirement to re-invest all capital goods without sufficient flexibility to react to changed external circumstances (Leontief, 1953; Brody, 1970; Tsukui and Murakami, 1970; Jorgenson, 1998; and Steenge and Thissen, 2005). To overcome such limitations, (Duchin and Szyld, 1985) proposed an alternative dynamic model. Their model requires an additional variable, i.e. explicitly focusing on a sector's available productive capacity. In the model a sector invests in expanding its capital stock if and only both its output is growing *and* its capacity is fully utilized; if either condition is not met, expansion investment will not take place. So, the production of goods for investment purposes depends not only upon final demand but also the sectoral rates of capacity utilization. The model also allows for changes over time in the coefficients matrices, as indicated by the subscript *t*. The simplest version of this model, assuming a one-year time lag for all capital goods, can be written as:

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[57] We should remark that the mathematical properties of the closed dynamic model closely resemble those of the open model, see Brody, 1970.

$$\mathbf{x}_t = \mathbf{A}_t \mathbf{x}_t + \mathbf{B}_{t+1} \mathbf{o}_{t+1} + \mathbf{f}_t \qquad [5.17]$$

or

$$(\mathbf{I} - \mathbf{A}_t)\mathbf{x}_t - \mathbf{B}_{t+1} \mathbf{o}_{t+1} = \mathbf{f}_t \qquad [5.18]$$

with

$$\mathbf{o}_{t+1} = \max\ [0; \mathbf{c}^*_{t+1} - \mathbf{c}_t] \qquad [5.19]$$

with

$$\mathbf{c}_{t+1} = \mathbf{c}_t + \mathbf{o}_{t+1} \qquad [5.20]$$

Here (dropping the time subscript): **A**, **B**, **x**, and **f** are as defined before, **c** stands for capacity, and **o** for desired addition to capacity. The vector $\mathbf{c}^*_{t+1}$, the desired capacity for period (t+1), is separately projected as a moving average of recent past rates of growth of output. The initial conditions include values for the vector **c** at $t=0$, and for the vectors **c*** and **o** at $t=1$. The full model includes additional equations representing factor inputs and a price equation, also with time-specific coefficients matrices. We again recognize, after rewriting, the basic form [5.11] in [5.18].

The dynamic model described by the equations [5.18]-[5.20] and the corresponding price model (not discussed here) can be used to analyse scenarios based on alternative assumptions about the exogenous variables such as **f**, the technical coefficients, the rates of capacity utilization, and the interest rate (as modeled in the price equation). The model can be employed to calculate outputs and prices on a yearly basis, where changes in output will define investment at the sectoral level.

Brody (1970) offers an interesting link between the flow dimension of the **A** matrix and the stock dimension of the **B** matrix. To that end, we define parameters t_{ij} where:

$$b_{ij} = a_{ij} t_{ij} \qquad [5.21]$$

where i and j stand for, respectively, selling and receiving sectors. That is, capital investment stands in a technologically determined relation to the flow outputs as registered in matrix **A**. We may think here of depreciation allowances which, in this form, determine so-called ‘turnover time’. For us is relevant that this link allows a direct interpretation of the growth parameters in terms of the circular flow characterisation of the input-output model we discussed earlier.

5.4. CHALLENGES AND LONG-RUN ASPECTS

Returning to what we outlined in the previous Chapters, disasters cause problems throughout the entire economic system, where the disturbed elements of the system trigger a separate chain of events, interconnected with other causal chains induced by subsequent actions and reactions. The input-output model has a number of limitations and challenges, which come to the fore in the analysis of disaster consequences. For example, in disaster analysis, changes in pre-disaster production levels will, through the fixed coefficients assumption, translate directly into a change in the sectoral demands for labour. A shift in these will translate into a shift in final demand, and so on. Subsequently, multiplier effects will enter with consequences felt throughout the economy. Clearly, without additional information it is problematic to analyse in which way the pre-disaster balanced economy will change. The main reason is the exceptional nature of the events studied. Input-output proportions established under 'normal' conditions in equilibrium will change, but in which way is difficult to anticipate, in particular because of the multitude of interacting multiplier effects; (small) shifts in intertemporal behaviour of economic agents in the immediate post-disaster period may completely upset traditionally expected patterns of outcomes. It is clear that further assumptions or, probably, hypotheses are required if we want to pursue our modelling effort along these lines. Below, we shall outline a number of input-output restrictions for disaster analysis in this Section. Let us recall the standard formulas in the previous Section, in particular:

$$\Delta\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\Delta\mathbf{f} \,. \qquad [5.13]$$

which describes the relation between changes in input requirements, and changes in final demand stand. Very often, the analysis of changes in policy or economic structure begins from the model formulation like [5.11], where coefficients or multipliers are present. We noted in the previous Sections that final demand categories are viewed as being determined exogenously. The above formula thus allows us to assess the effect on the economy of a change in **f**. For example, we may study the effect of a change in the investment level due to a switch in spending, as a consequence of a natural disaster. Such changes in investments now are translated via the respective Leontief inverse $(\mathbf{I} - \mathbf{A})^{-1}$ into changes in outputs of the industrial sectors in the region. It is important to bear in mind here that the term 'impact' or step-wise analysis is used when the exogenous change is caused by one 'impacting agent' (or a small number of such agents) and when the changes are expected to occur in the relatively short run (e.g. next period). This means that such an analysis suits well for a relatively simple small-scale, short-term economic shock examination when production coefficients are supposed (and assumed) to stay unchanged.

Once we attempt to introduce a vast, large-scale heterogeneous shock, a number of basic input-output modelling assumptions may become questionable. The scale of the disaster plays the key role in determining the shape of the model. This is an aspect that seems to be less covered in the literature, in the sense that size usually is not treated as a separate factor. *In concreto* we may think here of small island economies being hit by a devastating hurricane, but also of devastating floods such as experienced by a heavily industrialized country like the Netherlands in 1953. In disaster research, this would mean that 'equilibrium' for a period of time has to be replaced by 'disequilibrium' and ‘connection by ‘disconnection’. Noteworthy is also that consequences of a large-scale event cannot be seen as a sum of consequences produced by a number of minor events[58]. As we discussed in Chapter 2, such a major calamity places the functioning of the whole economic system under pressure, while minor events have only marginal impacts. Soon it becomes clear that standard input-output exercises can no longer support such large-scale shock analysis. This stems, firstly, from the presence of rigidities triggering persistent disequilibrium on the markets in the face of disaster (see the discussion in Chapter 3); secondly, from the complexity of the economic consequence scenario(s); thirdly, from the time range while the economy is under effect; and fourthly, from the need for efficient resource reallocation in disaster aftermath.

As noted in the discussion around the choice of model in the previous Chapter, disequilibrium and loss of connections within an economic system after a calamity are a common problem for disaster modelling. However, they are difficult to cope with conventional modelling tools, as normally models are based on balancing principles. A disaster, resulting in the breakage of existing ties within an economy and pushing it out of the established equilibrium for a significant period of time, is the first challenge we have to deal with in the construction of our own model. This implies that we have to think in novel ways about the current notions of equilibrium and disequilibrium. This raises the fundamental question on how to define and/or interpret an input-output model, which could perform sectoral studies of an economy under ‘extreme circumstances’.

Next, there is the issue of the nature of the shock. Essentially, by the very definition of disaster (see Chapter 2), the shock is too substantial, and significantly outweighs the shocks modelled in other cases. Such a disturbance in a complex modern economy would cause a chain reaction, and most probably, undermine the assumed stability of the established flows, while in the studies of economy-wide effects of relatively minor impulses, it is assumed that the economic system under examination is robust, i.e. the basic structure stays stable. Heterogeneity of a shock will inevitably lead to the emergence of disproportions within the system, which will have to be ’addressed’. The second challenge in our modelling is to deal with the emerging disequilibrium and look for new proportions within the system that would make it work again.

Besides, when long-term effects and broader changes are examined within an economy following a severe adverse shock, we are basically dealing with projections and forecasting of an event with unknown consequences. Here we face a serious problem. As the period of projection increases in time (for example, modelling the longer term effects on a development trajectory) and the number of assumptions increases, the accuracy of a projection exercise tends to decrease. This is a consequence of a diminishing ability to accurately forecast the new final demands (i.e. the elements of **f**), and of changes in production structure (in fact, the elements of **A**). In the normal situation, a firm can sell part of its product to other manufacturers and part of it to final users. The relative proportions between these parts are the resultant of many factors, which, apart from economic ones, include political, sociological and historical elements. At the same time, a firm buys its inputs in specific proportions from other

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[58] This statement was one of the conclusions of a three-day workshop on methodology on damage estimation held in 2003 in Delft, the Netherlands. For further reference, see Van der Veen, Vetere Arellano and Nordvik (2003, pp289-290).

manufacturers and employs the necessary amount of the primary inputs. The catastrophe, by its very nature, will destroy part of this economy-wide network. It is not obvious *a-priori*, what will happen if a firm is confronted with the fact that some (or most) of its customers or suppliers are lost, on a temporary basis, or perhaps forever. At the same time, new players can arrive or unexpected markets can emerge, possibly signalling new opportunities. At the national or sub-national level it is almost impossible to predict what will happen because issues are embedded in a much wider setting. Disasters, as one-time events, are very difficult, often even impossible to predict, and thereby assess the changes that they impose upon an economic system, as well as its pattern of reaction and recovery. Clearly, post-disaster economic policy needs to steer the distribution of the available goods in appropriate ways between various categories of buyers and suppliers. For instance, a policy choice in favour of relieving shortages in final demand may alleviate problems of the targeted groups, but at the same time may increase inter-industry imbalances. This shows that choices are not straightforward, and involve complex interrelations and interactions.

The needs for clearly defined goals and well-communicated policy in the early disaster aftermath are triggered by the existence (and, in fact, strengthening) of the rigidities, which we discussed in Chapter 3. What these point at, is that an economic system under stress is severely damaged, the network of circular flow is disturbed, and little is known of what will happen next. It is due to the uncertainty that the markets are slow and have difficulty to find their clearance point. Looking for ways to find suitable policy directions forms the third challenge for our modelling exercise. The outlined challenges require us to take a different approach to fulfil the modelling needs of disaster analysis. We can conclude the following: to address the first challenge, the modelling of a disequilibrium situation, we need to find a way to account for the assets left after the outbreak of a calamity, while relaxing the balance assumption.

The last challenge can be addressed by scenario analysis, often a formalised version of so-called ‘what if’ inferences. These have become an essential part of business decision-making, and are currently widely used in areas such as asset-liability and corporate risk management, and research and development over medium- and long-term time frames (see Harris and Schwartz, 2002). This technique appears to be most suitable for studying events with a low frequency of occurrence, which nevertheless result in substantial, even irreversible, consequences (such as climate change, the depletion of fossil energy resources, pandemics or ageing), or for the analysis of large-scale policies with major impact (like controlled emissions of CO_2, policies aimed at sustainable development, economic integration and trade). New visions are suggested, among others, on scenario analysis done in various fields, for example CPB (2006), Duchin *et al.* (2002), Swart, Raskin and Robinson (2004), Van Genugten, Heijnen and Jager (2002). Although scenario analysis is often used in disaster (economic) analyses, it is sometimes not yet recognised as a formal tool. Here, the abundance of assumptions in cases where data are scarce and often incomplete, and where analysis is complicated by the presence of too many unknowns, often can be replaced by the analysis and comparison of various disaster situations under various circumstances. This way, policy analysis will not result in a straightforward answer; rather, scenario analysis offers distinct borders within which outcomes can be deemed reliable. The formulation and analysis of alternative scenarios incorporating documented, exogenous assumptions bound by internal consistency is a promising approach to shed light on feasible options for policy and action. Projections about changes in production coefficients, the pattern of demand as well as resource relocations (and, also, the impossibility thereof) during the disaster aftermath and recovery can be featured in various combinations, tracing their impacts throughout the economy. Simulating various situations and events can reveal important impacts and help identify those ‘bottlenecks’, which can be avoided if policy measures are taken. Formulating scenarios may help illustrate the merits and potential of disaster analysis, in particular in the input-output setting, employing the structure and insight of the latter into the complex issues at various levels, from global to local, which input-output has to offer. Essentially, input-output with its strong technology tie can be well complimented by scenario approach. Scenario analysis offers more controlled flexibility without undermining the integrity and transparency of the basic model, while at the same time broadening its possibilities. Scenarios are also a prominent tool to structure our thinking on the identification and formulation of credible research questions and hypotheses, which are just as meaningful and ingenious. Particularly in the form of so-called turnpike trajectories (see Dorfman, Samuelson and Solow, 1958), optimal paths have been studied in the context of growth and development questions. Turnpikes describe the path an economy should ideally follow, *given* a clear objective (that is: the economic decision makers should know where they wish to be going), and *given* transparency of the constraints, see especially Tsukui and Murakami (1979). Also, for exploring further the role of scenarios within input-output context, dynamic input-output can be made use of; like the version described in Section 5.3.

5.5. SUMMARY AND DISCUSSION

In this Chapter, we recapitulated the basic constructions behind the standard input-output framework. Based on the input-output table, where the transactions between various actors on the economic scene are recorded, both on the production and consumption part, an input-output model can be formulated as expressing the dependence of the total output of goods on the final demand for these goods. The main line of thinking is that any increases or decreases in final consumption would cause ripple (multiplier) effects throughout all the sectors of production, in reaction to changes in demand. This is what is referred to as demand-driven model, where the multipliers matrix is referred to as the Leontief inverse.

The main findings of this Chapter are on the implications of model constructions for disaster modelling. We showed that there are a number of features in a basic input-output model, which are most important for our intended analysis. Essentially, the question is how far we can use the merits of input-output framework in economic disaster analysis and where adjustments are necessary to capture the reflection of a disaster phenomenon. We formulated a number of challenges to be addressed and overcome in our modelling Chapter, i.e. the reflection of disequilibrium; the emergence of disproportions; the choice of policy goal in the post-disaster modelling in the view of post-disaster rigidities. We suggest that the input-output approach can be supplemented by scenario analysis, opening a wide field of opportunities and hypothesis formulation for the situations where outcomes are unknown. With the established methodological background, we shall continue with the core of our investigation in the next Chapter, i.e. model building for the analysis of disaster consequences, recovery options and policy measures.

Appendix 5A

Input-Output and Geography

5A.1. Compilation of Input-Output Tables

Input-output tables are compiled in many countries around the globe. They are built by official statistical offices, specialised official or semi-official institutions such as national banks or universities, private companies or individual researchers. There exist several methods to build input-output tables, which all share a number of characteristics. There is a close connection to System of National Accounts, which guarantees internal consistency of the tables and consistency with the national totals on the macro level, such as gross or net national income or product. International organisations such as UN, OECD or Eurostat have played an important role in issuing guidelines for the national accounts. In 1968, the United Nations issued guidelines for a new overall framework, which still forms the basis for today's system. This new system integrated the production data in two matrices, the make matrix and the use matrix.

Several stages can be distinguished in the building process, where each of them requires specialised expert knowledge. The first stage consists of organising the data sources such as on individual firms, investments, wages, consumer behaviour, import and export. These data are incorporated into specific formats that provide the building blocks for the tables. The make-use system makes an explicit distinction between commodities and industries. The use matrix has a dimension (c x i), while the make matrix has a dimension (i x c). Thus, the make-use framework often is rectangular, distinguishing more commodities than industries. A big advantage of it is that industries characterised by multiple production now can be easily accommodated without a-priori dealing with complex allocation problems. A drawback is that the economic modeller now faces the task to build an input-output table on the basis of two matrices. Various methods have been developed to do this. Well-known are the methods based on the so-called commodity technology assumption and the industry technology assumption. They generate tables of dimensions (c x c) and (i x i), respectively. If one opts for an (c x c) table (as we do), the technological interconnections are stressed, while opting for an (i x i) table stresses the institutional aspects.

After the data have been incorporated in the make-use framework, the stage of balancing or integration begins. That is, the corresponding totals in the make and use tables must be corrected to give the same row or column totals. This is a labour-intensive stage, because many sources of error, such as incorrect data or classifications, or complex 'border cases' must be addressed. A separate issue forms deciding on appropriate definitions of commodities and industries. Both (*c* x *c*) and (*i* x *i*) methods have their own merits. Most important is that they are internally consistent, and consistent with the broader system of national accounts.

In fact, as we mentioned above, input-output tables are compiled based on the very detailed data of individual economic agents, such as enterprises and households, which are then aggregated to the desired level (regional, national or even global). Due to this aggregation, in fact, the inherent geographical component of input-output tables becomes to some extent latent. Yet, in economic modelling, we are often faced with decisions and actions that have explicit geographical dimension. Current technological developments in the field of earth observation offer a solution to this issue. By means of so-called geographic information systems (GIS), the link with the real spatial format can be recovered, and geographically-related features may be brought into the up to now ‘spaceless’ models. The routes of input-output tables in the micro-level data provide an excellent basis for infusing more geography into this modelling framework. We shall provide a short description of the GIS below.

5A.2. Geographic Information Systems

Recently, the so-called geographic information systems are gaining more prominence in various research fields, expanding the possibilities of models and methods by installing the link between the abstract theoretical world of models and real-life geographical component, which was not there before. We shall briefly introduce the geographic information systems, and reflect upon the opportunities it opens for achieving our modelling aims.

A geographic information system is a computer-based system that enables capturing, storing, analysing and displaying various sorts of geo-referenced information, i.e., data that is identified according to its location (i.e., latitude, longitude, and perhaps elevation). Data capture is in fact identification of objects on the map, their absolute location on the surface and spatial relationships. The analysis part consists of the possibility to lay links and combine information via the geographical attribute. GIS thus enables integrating mapped variables, construction and analysis of new variables. GIS is also able to analyse spatial relationships and determine the adjacency between the objects (what is next to what), containment (what is enclosed by what) and proximity (how close or far is something to something else). Mapping data within GIS involves in fact a complex conversion of data from the satellite images into digital data that should be able to reproduce maps. Displaying data requires the ability to locate (analysed) thematic data back to a map. GIS technology is in fact enhancing the efficiency and analytical power of traditional cartography. Wall maps, interactive maps, animations and other graphical products that can be generated within GIS allow better visualisation, thus heightening the ability to extract and analyse information. Images retrieved from GIS are also a more effective tool for the communication of results, often conveying technicalities in a comprehensive manner also to non-scientists. GIS technology is therefore becoming an essential tool in the effort to gain more insight into various processes and events provided its capacity to explicitly include spatial dimension.

In the GIS environment, it is possible, pointing at some location on a map (or screen), to retrieve information about it from offscreen files containing layers of attribute information. Each layer represents a particular theme or feature of the map.

Such systems may, for example, include information on such attributes as topographic features (like elevation, slope and orientation, *et cetera*), demographic attributes (age, gender, education level, *et cetera*), economic attributes (like type of economic activity by sector, number of production facilities per sector, number of employees, value added, *et cetera*), as well as others. This means that with a GIS one can link thematic attributes to location data, such as people to addresses and buildings to streets. Using ‘intelligent’ digital maps, one can then layer thematic information on top of one another to obtain better understanding of how complex reality works altogether within the same geographic area. Each layer, in fact, can be switched on or off, which is controlled by the end user of GIS. One chooses, which layers to combine based on the questions one needs to answer (US Environmental Systems research Institute, ESRI, 2002). For example, GIS can be utilised in numerous fields, such as agriculture for spatial analyses of agronomic data; in banking and commerce for gaining insight into sales, inventories, product logistics, customers’ profiles, purchasing habits, financial behaviour, and needs for additional products or services; in utility sector for modelling electrical, gas or water supply systems; in health care for the studies of epidemiology and mapping health care system; in insurance for risk visualisation, analysis and distribution; in transportation for infrastructure management, fleet, logistics and transit management; and many more. GIS also opens new possibilities in study and academic research: most of the problems facing the world toady, either of environmental, economic, political or social nature, exist in geographic context. GIS technology is therefore able to meet the most topical needs for the analysis of issues on today’s research agenda, and will undoubtedly become one of the most demanded research tools in academic circles.

Being not an end in itself, a geographic information system is rather a means to integrate a variety of information and applications with a geographic component and create a single manageable system capable of reflecting the multi-layered reality. For example, we may first locate production facilities within a zip-code or a region, and then link each of them to the number of employees, output, or profits for the purposes of evaluating their importance in regional or national economy. Another example is the field of risk and emergency management, where GIS is already widely used as one of the critical tools of research. Here, for instance, response time of fire and rescue squads, victim evacuation or traffic congestion can be analysed, making an overlay of the location of residential and industrial areas, road system and the information containing road capacity. Combining all these data, it would be possible to pinpoint the exact locations of bottlenecks for rescue squads or evacuation streams, and seek for better solutions. Evidently, the backbone of GIS is good data; inaccurate data can result in inaccurate models and maps, skewing the outcomes of analyses and ultimately resulting in poor decisions. A number of institutes and research centres worldwide are putting effort into the advancement, collection, capture and processing of data. Among many, ESRI, USGS in the US; SPINLab (VU University of Amsterdam), Geolab (Technical University of Delft),[59] and Geodan consultancy in the Netherlands can be mentioned.

Summing up, the power of GIS is the ability to relate different information in a spatial context. GIS can be used, *inter alia*, for scientific investigations, resource management and development planning. Because this technology allows combining geo-referenced data from different sources, at a scale that was not possible before, it can

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[59] TU Delft has launched the Gomatics master programme in 2005, specialising in the combination of the science and thetechnology of three-dimensional measurement, visualisation and analysis of geo-information.

reveal important new information and thus can improve the factual base used for decision-making. An active and broad market for GIS technology and its application nowadays facilitates the lowering of costs connected to data acquiring and processing. In addition, continual improvements in GIS hardware, software and data, are expected to lead to an even wider span of application of the technology throughout government, science, business and industry.

GIS has excellent development and application potential for future research and practice, as new insights that can be gained within GIS environment, are providing the explicit link with the geography component that was often missing so far. Following US Geological Survey institute (USGS, 2006), environmental studies, geography, geology, planning, business marketing, social sciences and other disciplines will keep on benefiting from GIS tools and methods. Together with cartography, remote sensing, global positioning systems and geography, the GIS is evolving into a discipline with its own research base known as geographic information sciences.

Chapter 6

Input Output Modelling of Big Disasters: the Proposed Approach

6.1. INTRODUCTION [60]

In this chapter we shall focus on mathematical modelling of disruptions in the economic structure in the immediate aftermath of a major disaster. Thinking about *large-scale* disruptions is central in this Chapter. Input-Output, as the chosen framework, will act as a guide in our inquiry.

The basic structure is again provided by a visualisation of an economy as a complex circular flow system with numerous interrelations between producers and consumers. Under the usual (pre-catastrophe) circumstances, it can be described in terms of a fine-tuned network of supply-demand relations, which determine quantities bought and sold. The disaster causes a sudden breakdown in this network; part of the system becomes dysfunctional, and the surviving parts need to adjust to the new circumstances.

We shall start with a number of observations on the principles and backgrounds of disaster modelling in the input-output framework. An integrative model for disaster economic analysis will be introduced, accompanied by a numerical example. We shall put forth the building blocks focusing on the immediate post-disaster situation in terms of system imbalances and disproportions. Hereafter we shall discuss the recovery stage, followed by elements of a cost-benefit analysis of potential prevention policies. We should point out again that this is not a fully-fledged model yet. However, it will provide the methodological core of a new approach with ample development potential.

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[60] This Chapter is largely based on earlier studies of ours on the consequences of a hypothetical big flood in the densely populated and heavily industrialised Western part of the Netherlands (Bočkarjova *et al.*, 2004a,b; see also van der Veen and Logtmeijer, 2005), as well as the article by Steenge and Bočkarjova (2007). These studies in particular made us realize the crucial role of rigidities in thinking about large-scale disasters.

6.2. DEFINING THE PROBLEM

As we know, input-output modellers interpret a circular flow in a special way, which requires some words at this stage. To this end, we would like to refer to Figure 3.2. The model's basic form, the standard, open input-output model, distinguishes two categories of destinations for commodities, i.e. *intermediate demand* by industries and *final consumption.* These two categories form the point of departure for our disaster analysis. Intermediate demand reflects the needs of each industry for products from other industries. Final demand consists of categories such as households' consumption, business and government investments, exports and inventories. Correspondingly, also two categories of inputs are distinguished, *intermediate* and *primary inputs*. Intermediate and primary inputs taken together for a specific industry are interpreted as production functions. Primary inputs include expenditures on the so-called input factors like labour, depreciation, imports, and, to a certain extent, taxes and subsidies.

We shall pay particular attention to one of the primary input categories, labour. Labour occupies a special place in disaster analysis, because it is different from the other input categories. For example, residential areas may be more severely affected – with many victims- than the industrial or service quarters. Economically, this would mean that firms lose part of their markets, with many consequences. This also means that if the stricken quarters harbour a substantial part of the work force, required primary inputs are momentarily unavailable. Even if production facilities remain intact, this situation causes a mismatch between the unavailable primary production factor (labour) and the intermediate inputs. Vice versa, it also may be possible that the workers have withstood the shock relatively unharmed, while their work places are heavily affected. In that case, there is another sort of mismatch between the inputs: labour is sufficiently available, but it cannot be employed because of the displaced production facilities. At the same time, we may observe imbalances between the two demand destinations. As in the last case, while final demand is still in place (because people would survive and thus need to satisfy their demands), intermediate inputs are not available to produce the required goods and satisfy this demand. Unless spare labour is employed elsewhere in the economy, it will remain idle, or decide to move to the area where labour market offers more employment opportunities.

In any case, we shall employ the fact that labour has properties, which make it different than the standard production facilities. In addition, there is another issue that we will address. Safeguarding full employment is one of the most important policy goals in modern economies. We shall address the question what this mans in terns of model choice when we are discussing the rigidities that we want to account for in our modelling effort.

Because disasters by their very nature are complex events, we suggest a split into a number of stages. In fact, we propose to distinguish three steps. First of all, understanding the disequilibrium emerging in the immediate disaster aftermath is a 'must'. Although it seems like a justified step following from disaster logics, many conventional economic models fall short in depicting disequilibrium, as mostly they are based on balances and marginal shocks. Our modelling effort concentrates on the mismatch between intermediate and final demand categories in the disaster aftermath.

Next, it is important to realise that an economy is not always able to achieve a new equilibrium position 'on its own' within reasonable time, given the scale of the shock that we are considering. A most recent example provides New Orleans recovering after hurricane Katrina. One year after the disaster, the Brooking Institute refers to the situation in the area as ‘stagnant’ in both public and private spheres (Liu, Mabanta and Fellowes, 2006) and ‘making a slow comeback’ (Liu, 2006). Further, an uncertainty in terms of market behaviour is described (Liu, Fellowes and Mabanta 2006, p.13).

> “To be fair, one year is not much time to turn around a city devastated by such storm. But, one year can be a long-time for the market […]. In short, much work is needed […] to boost market confidence in New Orleans and move the region’s economy affirmatively forward.”

Moreover, the conditions in which the disaster may unfold can vary greatly, which means that there is actually no single recipe for recovery. It becomes clear that modelling disaster consequences implies a significant need for data about economic agent behaviour, the precise circumstances and the processes present in the disrupted system after a shock. Besides detailed data and information systems, ‘understanding’ and ‘analysis’ (see Petak, 2006) are especially asked for in disaster management. This already seems to suggest that *multiple* recovery paths should be analysed under various conditions and circumstances. This is also essential for policy-making in steering the economic recovery back to a situation of equilibrium.

Knowing the options and possibilities in advance for an economy to recover should facilitate the structure of reconstruction and recovery in the disaster aftermath when decisions have to be taken fast and efficiently. Yet, the time pressure and public expectation that are experienced by officials together with limited information in calamity aftermath make decision-making extremely difficult. This means, that knowledge about vulnerability of an economy to large-scale shocks, its resilience potential to get back on track and the desirable recovery options, have to be prepared in advance.

To provide a solution to the issues mentioned above, *ex ante scenario analysis* is indispensable. The formulation of scenarios with respective hypothesis and assumptions underlying each of them is one of the ways to address high uncertainty. Choices in favour of one aspect of recovery may restrict the possibilities elsewhere due to the limited availability of resources. In input-output terminology, stimulation of final demand consumption with all means may alleviate temporary needs, while this may imply a crowding out of domestic industry in the long run due to imports substitution (we touched upon this in Section 3.2.4). In the current study, we shall outline the possibilities for modelling a return to equilibrium, as well as the need to concentrate on a specific option, such as restoring the pre-disaster situation. In many respects, analysing the return to pre-catastrophe balances and proportions can be seen as a threshold for damage estimation. That is, this comparison can show where the economy could have been, had the disaster not happened.

Finally, for the country to be prepared for a potential hazard, precautionary measures should be considered. We discuss this as the third stage in our modelling effort. Weighing economic costs to be made to implement a particular mitigation measure against the benefits to be gained in the future (often in the context of disaster preparedness) should underlie policy decisions where such analysis is appropriate. Here we also refer to the issue of expressing losses in monetary terms, which may well be applied to industrial loss, but is a much more intricate issue in cases of assessing human life or psychological damage. We shall attempt to gain insight into the economic performance of a society, concentrating on production capacity and the loss thereof.

Before proceeding, we would first will clarify a number of assumptions behind our approach.

6.2.1. Assumptions

Our approach in this Chapter will have a definite geographical basis. To include this aspect, we shall, for the moment, introduce some specific assumptions (which may be relaxed in later work).

We shall assume, first, that all economic capacity is embodied only in the productive elements comprising the economic system. That is, in the activities involved in the production of goods and services, employing both labour and capital, and producing value-added. Often the concepts underpinning economic theory are neither tangible, nor directly measurable; terms like welfare or utility are good examples here. Featuring such concepts in quantitative models may bring in an unwanted degree of obscurity, and require 'indirect' operationalisation by means of proxies. Here, thus, we shall only deal with 'tangible' categories of productive activities. Input-output analysis addresses these activities traditionally in terms of so-called sectors or industries. A sector normally consists of a substantial number of 'similar' production establishments. Essentially, input-output modelling presumes that all firms within an industry have approximately the same production function, the industry production function. In practice, this function is some appropriate average of numerous individual (firm) production functions. To obtain the individual firm functions, one thus has to go back to the original data underlying an input-output table. Following this road means that it is data availability that ultimately determines the level of precision. (An appropriate definition that recognises the possible aggregation biases involved in defining a 'sector' may replace the present one in later work.)

Second, we assume for the moment that individual plants are either completely gone or completely undamaged in the disaster aftermath. The simplified discreet division between either entirely lost or completely undamaged facilities in our case is a simplification, of course. In the real world, there exist many in-between options, like partly damaged buildings with various degrees of severity. This is the usual outcome of, for example, earthquakes or floods, when closer enquiries reveal a great number of partially destroyed buildings with detected deficiencies in construction as a result of ground motion or humidity. Detailed examinations and surveys then are necessary to bring real damages up to the surface and are important for direct loss estimations. Within the scope of our thesis, we shall also assume that direct loss estimation requires a 'mere' measurement,[61] and is available to modellers to provide more inference into the indirect repercussions of direct losses throughout an economic network. This means that at this moment, we shall simply assume that the post-catastrophe economy consists of two parts, i.e. a part that has remained undamaged and is in principle able to continue production activities (unless restricted by inputs missing from the 'lost' areas), and a stricken part that is completely lost in terms of production capacity, temporarily or forever. A consequence of the second assumption is that if a sector or industry looses $100\gamma_i$ percent of its capacity, it looses also $100\gamma_i$ percent of its employment

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[61] We have outlined the difference between measurement and inference in Chapter 3.

opportunities. We shall relax this assumption in Section 6.6, where we shall allow labour to decrease independently of sectoral capacity disturbance factors.

Third, and perhaps most drastic, we assume that an undamaged production facility still has access to all its pre-disaster workers. This assumption avoids a further array of complex and interrelated effects. For example, if the factories would have survived without their work force, this would induce, on the one hand, extra demand for labour, and we would have to discuss transfer, re-schooling and re-training issues. On the other hand, production establishments without employees would be forced to stand still, which implies extra losses till the time labour has been re-supplied. At this stage, we decided to abstain from these issues. This allows us to focus exclusively on one particular type of mismatch, i.e. the mismatch between the 'surviving' establishments' production capacities and households' demand for consumption goods, i.e. the final demand categories. This choice also is motivated by what we conceive of as 'rigidities' in the modern, highly industrialized types of economies. The next paragraph will go into this.

Fourth, experience has taught us that multiple *rigidities* exist in modern economies. In our contribution, we have considered rigidities in Chapter 3, thereby referring to conditions that prevent discrepancies of supply or demand to be solved relatively quickly by the market forces. One possibility may be the presence of inelasticities in the supply and demand factors. In our case, also the sheer size of the catastrophe, in combination with the low frequency of its occurrence, may provide another explanation. In particular, in a post-disaster situation, when the economy is out of equilibrium, rigidities will manifest themselves even more fierce. Time in itself also may be a cause of rigidities. Time is be necessary to restore broken economic links in case new suppliers, customers or markets are to be found; or time needed to ship the goods from abroad, also in the light of new scarcities of certain resources on the market relative to others; time for adjustments in technology, where input substitution is possible. However, production processes where substitution is less likely (for example, if they depend on a damaged or destroyed key sector), will cause 'bottlenecks', braking recovery efforts throughout the economic network. Also, there may be failures of the so-called lifelines infrastructure, be it roads, electricity or telecommunications. An inability to use these facilities by productive sectors and the population at large may be another contributing impeding factor. Other institutional factors may reveal the lack of information; pre-set contractual obligations, or government intervention in the form of a price ceiling or rationing for a set of basic products.

6.3. THE CIRCULAR FLOW REVISITED

We mentioned in Chapter 4 that it is advisable to adopt a modelling framework that is flexible enough to address specific issues in the wider setting of a country struggling with severe disruptions. This has led us, as explained earlier, via a number of steps, to select input-output as a basic framework. Further, in Chapter 5 we have discussed the standard formulation of this model and outlined its advantages and limitations. In this Chapter, we are going to adapt the input-output framework to fit the needs of major disruption modelling, thereby exploiting the model's characteristics to our advantage.

In the coming Sections, we shall follow an approach distinguishing *three* steps. We shall propose that such an approach offers a convenient point of departure for the *three* tasks we have set in the beginning of this Chapter. The first issue is how to deal with the lost productive capacity in the immediate disaster aftermath. This stage aims at getting a proper perspective on the nature of the post-catastrophe disruption, which should result in a representation of a concise picture of the situation. Our second task is addressing the options for selecting a recovery path. During this stage, the economy has to decide in which way it wishes to rebuild and reconstruct its productive infrastructure. Many options exist, and it is not always clear which ones should be preferred. Specific problems in selecting a recovery path should be discussed. Finally, our task is to offer an outline of a cost benefit analysis (CBA) of selected precautionary measures, in line with our approach. In the last stage, *ex-ante* policy decisions should be linked to the planned for post-disaster sectoral and national performance.

We shall devote this Section to the analysis of the first stage of our approach, namely gaining insight into the immediate post-calamity situation within an economic network. We recall the introduction of the Leontief model in Chapters 3 and 5 (see equations [3.1] through [3.4] and [5.1] through [5.14]).

Despite its transparency, this model is not very clear in the way it deals with labour *as a production factor*. In the standard (open) interpretation, final demand is bought and consumed by households, which in turn provide the labour force that the economy needs. Labour, in this model, is in infinite supply. That is, any increase in demand for labour is met instantaneously. Similarly, any decrease in employment is met by the system without any problem: labour that becomes superfluous simply drops out of the system.[62]

Clearly, the model also informs us about employment and employment opportunities (instead of 'only' about final consumption). To bring about this dimension more clearly, we shall reformulate the model. The reformulation also is aimed to better focus on the 'rigidities' that we referred to earlier. In particular, we mean here the relation between the labour inputs and final demand. One of the rigidities will be the interpretation of the final demand vector in terms of an aggregate real wage bundle of 'prescribed' proportions.

In fact, we propose to present the above open model in a different way, i.e. by employing a representation employing the *real wage*. The real wage per worker is, by definition, equal to the consumption package that this worker can buy for his money wage. Because all workers have identical preferences and earn the same wage, we can denote this package by the symbol **h**. We then have:

$$\mathbf{h} = \left(\frac{\mathbf{f}}{L} \right) \qquad [6.1]$$

Recalling [3.2], this allows us to write the model ([3.1], [3.2]) as:

$$\mathbf{x} = \mathbf{Ax} + \left[\left(\frac{\mathbf{f}}{L} \right) \mathbf{l} \right] \mathbf{x} \qquad [6.2]$$

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[62] Evidently, the problem of superfluous labour will resurface in other parts of the economy such as unemployment schemes. These schemes, by assumption, do not influence the basic system as given by [3.1] and [3.2].

The above equation provides us with an alternative description of the interconnections in the economy. We distinguish two matrices; one representing the conventional fixed intermediate input structure, the other one the real wage part. A comment is needed clarifying the dimensions of the matrix **H**:

$$\mathbf{H} \equiv \left[\left(\frac{\mathbf{f}}{L}\right)\mathbf{l}\right] \qquad [6.3]$$

where the '**h**-part' should be seen as $(1/L)\mathbf{f}$, where **f** is the familiar (n x 1) consumption vector, multiplied by the scalar $1/L$. Further, the row vector **l** has dimension 1 x n. This means that multiplication of the latter two terms yields the rank one matrix $(1/L)\mathbf{fl}$ of dimension n x n. Multiplied by the total output vector **x**, we obtain the *vector* **Hx**. The fact that all workers are identical implies that the proportions between the goods consumed within this matrix are the same across the sectors; however, the sectors will differ according to the relative weight of employed labour. The above equations thus provide us with an important link between labour and the intermediate inputs in the **A** matrix.

Bringing the two new matrices together, we obtain a coefficients matrix, **M**, where

$$\mathbf{M} \equiv [\mathbf{A} + \mathbf{H}] \qquad [6.4]$$

We observe from the equality above that **M** is a strictly positive matrix having dominant eigenvalue equal to unity. The total output vector is the corresponding, strictly positive eigenvector **x**.[63] We shall also make use of $\underline{\mathbf{M}}$, the corresponding matrix of transactions in *absolute* terms. It is particularly useful to have a division between both intermediate and final demand (i.e. consumption) parts per sector. Let $\hat{\mathbf{x}}$ again denote the diagonal matrix with the sectoral outputs x_i (i = 1,…,n) at its main diagonal. We now have:

$$\underline{\mathbf{M}} \equiv [\mathbf{A} + \mathbf{H}]\hat{\mathbf{x}} \qquad [6.5]$$

$$= \mathbf{A}\hat{\mathbf{x}} + \mathbf{H}\hat{\mathbf{x}} \qquad [6.6]$$

$$= \mathbf{Z} + \mathbf{F} \qquad [6.7]$$

where

$$\mathbf{Z} \equiv \mathbf{A}\hat{\mathbf{x}} \qquad [6.8]$$

stands for the inter-industry deliveries of goods and services, and

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[63] Recall that we assumed that **f** is strictly positive. Recall further that in Chapter 3 we used the same symbol **M** for the coefficient matrix of a closed Leontief model. Because there is no confusion, we have adopted the same symbol here to denote the coefficient matrix of a more complex Leontief closed model.

$$\mathbf{F} \equiv \mathbf{H}\,\hat{\mathbf{x}} \qquad [6.9]$$

for the workers' real wage.

We shall employ matrix **M** for a better understanding of the physical disruptions in the disaster aftermath. We concentrate on the proportions between the primary and intermediate inputs, where disturbances in both categories will bring disequilibrium into the system. Namely, damaged factories will not be able to produce output; at the same time, lost labour will not be able to consume goods in the degree it previously did. Working with matrix $\underline{\mathbf{M}}$ is an alternative to procedures such as adjusting coefficients matrices. In fact, what we envisage to do is not to feed the data on direct loss into the model the way it is often done, i.e. via a negative impulse on final demand, see *inter alia* Okuyama, Hewings and Sonis (2002), but rather to look at the influence of a shock on both intermediate and final consumption activities. This will represent a picture of the actual disruptions in an economic network in the situation immediately after a calamity. For this, we first will need the $\underline{\mathbf{M}}$ matrix. Only when we are ready with picturing the actual physical disruptions, we will proceed with the analysis of the indirect repercussions of production flow interruptions. In fact, we may write, combining equations [6.2] and [6.4].

$$\mathbf{x} = \mathbf{M}\mathbf{x} \qquad [3.6]$$

We note that equation [3.6] contains the same information as the set of equations [6.3] to [6.7], but now written as a *closed* Leontief model.[64] We should observe that the model of [3.6] is different from the open model we started with. Solving for **x** now addresses a question about the proportions that are needed for a circular flow where **x** stands for the bundles of total outputs *and* total inputs. That is, the solution to [3.6] gives us in a transparent way the proportions that are required for an uninterrupted circular flow. We also should observe that this circular flow will be disrupted if the proportions in the workers' real wage bundle would change – unless all industries adapt correspondingly, which is not to be expected. So, the 'rigidity' regarding the proportions of the consumption bundle now has found an interpretation in terms of not to be changed input proportions.

$$\underline{\mathbf{M}} \equiv \mathbf{M}\,\hat{\mathbf{x}} \qquad [6.10]$$

6.4. INTRODUCING A CATASTROPHE: MODELLING DISEQUILIBRIUM

Below, we shall develop our argument starting from our knowledge of the *location* of lost capacity. Geographically differentiated knowledge of the pre-disaster situation often is available from various sources such as offered by today's highly detailed GIS-data bases (see Appendix 5A for more information on GIS). Nowadays many types of

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[64] See also Chapter 3 on the notion of a closed model. A different type of closed input-output model is discussed later on when deriving an alternative Basic equation for describing the surviving capacity after a calamity.

such geo-referenced information systems exist. Within a so-called geographic information system one may store, analyse and manage spatial data and associated attributes. In other words, these systems contain data that have an explicit spatial reference like a coordinate or zip code. Such systems may, for example, include information on topographic features (like elevation, slope and orientation), demographic attributes (such as age, gender, or education level), economic attributes (type of economic activity by sector, number of production facilities per sector, number of employees, value added, *et cetera*), as well as other information. The development of GIS made it possible to work with extremely accurate data essential to estimate lost production and consumption capacity in the immediate post-disaster situation. Detailed GIS that contains geo-referenced economic data is called economic GIS (see for example Huizinga, 2003), and provides an opportunity to develop modelling techniques that make use of this particular type of information.

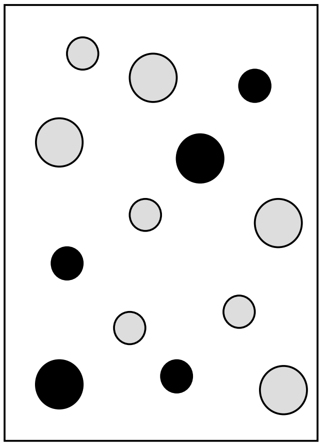

Figure 6.1. *Location of productive capacity in a pre-disaster economy*

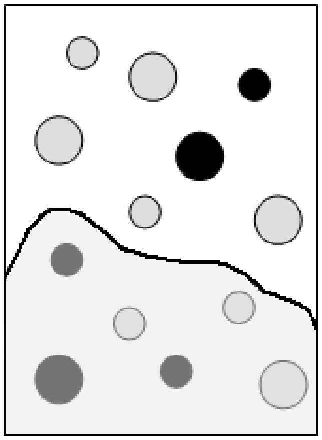

Figure 6.2. *Location of lost productive capacity in a post-disaster situation*

In our model, the extent of the shock caused by the disaster can be traced based to the information on the physical location of the *individual establishments* forming the sector; see also Bočkarjova, Steenge and Van der Veen (2007). We now shall use this knowledge to determine the post-disaster surviving productive capacity. We shall start with a small map schematically representing the economic infrastructure in a two-sector example, see Figure 6.1. The map depicts the location of each production site (establishment) in a fictive two-sector economy. Each dot represents an individual establishment, where the size of the dot varies according to the output value produced at each facility. The markings of the dots (black or grey) are indicative of the sector to which the plant belongs. Suppose now that a flood incapacitates a significant part of this country, as represented by the shaded area in Figure 6.2.

As mentioned above, the data on the precise location can be obtained from an appropriate GIS database, which can also be coupled to the economic GIS with information on the economic variables per establishment per grid, like employment, value added, total value of production, *et cetera*. With this information, one can aggregate the data from each grid within the disaster area up to the level of detail of the corresponding input-output table; for example, to the industry level in our case. Subsequently, this data on the incapacitated production value per sector can be related to the total production value per sector of the country to obtain the loss coefficient per sector. We shall introduce the parameter γ_i ($0 \leq \gamma_i \leq 1$) to indicate the fraction of production capacity lost in sector *i*. In matrix form, this yields:

$$\mathbf{\Gamma} = \begin{bmatrix} \gamma_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \gamma_n \end{bmatrix} \qquad [6.11]$$

We shall interpret this in the sense that, immediately after the shock, this particular sector is able to produce only $100(1 - \gamma_i)$ percent of its pre-disaster output provided the inputs required to maintain this production level are available in the right proportions. In matrix form we may express the surviving capacity as $(\mathbf{I} - \mathbf{\Gamma})$:

$$(\mathbf{I} - \mathbf{\Gamma}) = \begin{bmatrix} 1-\gamma_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1-\gamma_n \end{bmatrix} \qquad [6.12]$$

As mentioned in Section 6.2.1, we shall make one specific assumption to avoid a multitude of problems. That is, if sector *i* has lost $100\gamma_i$ percent of its capacity, we shall interpret this in the sense that also $100\gamma_i$ percent of its work force is lost or not available. This will result in an equation of the form:

$$\mathbf{t} = \mathbf{M}\ (\mathbf{I} - \mathbf{\Gamma})\ \mathbf{x} \qquad [6.13]$$

where the new symbol t will be explained in the context of equation [6.18], below. Note, that equation [6.13] resembles equation [3.8] to a certain extent. A major advantage now is that a reduction in the sector's labour input requirement directly translates into a corresponding reduction in final demand **f** as specified in [3.1]. We shall further assume that workers' preferences have not changed. That is, proportions within the final demand basket remain the same. We may also note that in the case of no disruption, matrix $\mathbf{\Gamma}$ is a zero matrix, and $(\mathbf{I} - \mathbf{\Gamma})$ becomes the identity matrix; as a result of this, equation [6.13] reduces to equation [3.6].

We shall now introduce γ_i and $(1-\gamma_i)$ into equation [6.10] with the aim to divide the initial pre-disaster economic system into two components. This will yield:

$$\underline{\mathbf{M}} = \begin{bmatrix} \gamma_1(z_{11}+f_{11})+(1-\gamma_1)(z_{11}+f_{11}) & \cdots & \gamma_n(z_{1n}+f_{1n})+(1-\gamma_n)(z_{1n}+f_{1n}) \\ \vdots & \ddots & \vdots \\ \gamma_1(z_{n1}+f_{n1})+(1-\gamma_1)(z_{n1}+f_{n1}) & \cdots & \gamma_n(z_{nn}+f_{nn})+(1-\gamma_n)(z_{nn}+f_{nn}) \end{bmatrix} \qquad [6.14]$$

or

$$\underline{\mathbf{M}} = \begin{bmatrix} \gamma_1(z_{11}+f_{11}) & \cdots & \gamma_n(z_{1n}+f_{1n}) \\ \vdots & \ddots & \vdots \\ \gamma_1(z_{n1}+f_{n1}) & \cdots & \gamma_n(z_{nn}+f_{nn}) \end{bmatrix} + \begin{bmatrix} (1-\gamma_1)(z_{11}+f_{11}) & \cdots & (1-\gamma_n)(z_{1n}+f_{1n}) \\ \vdots & \ddots & \vdots \\ (1-\gamma_1)(z_{n1}+f_{n1}) & \cdots & (1-\gamma_n)(z_{nn}+f_{nn}) \end{bmatrix} \qquad [6.15]$$

where we have separated the lost and spared parts of intermediate and final demand matrices. We now have the following expression, where the suffices refer, respectively, to the lost and spared parts of the economy:

$$\underline{\mathbf{M}} = \underline{\mathbf{M}}_{\mathrm{L}} + \underline{\mathbf{M}}_{\mathrm{S}} \qquad [6.16]$$

Equation [6.16] now provides a clear insight in the economy immediately after a disaster.

We now turn to $\underline{\mathbf{M}}_{\mathrm{S}}$, which is of particular interest for us in modelling the disaster aftermath. It gives us the information on the production capacity that survived a calamity. This matrix can be written, following equation [6.15], as the sum of two matrices:

$$\underline{\mathbf{M}}_{\mathrm{S}} = \begin{bmatrix} (1-\gamma_1)z_{11} & \cdots & (1-\gamma_n)z_{1n} \\ \vdots & \ddots & \vdots \\ (1-\gamma_1)z_{n1} & \cdots & (1-\gamma_n)z_{nn} \end{bmatrix} + \begin{bmatrix} (1-\gamma_1)f_{11} & \cdots & (1-\gamma_n)f_{1n} \\ \vdots & \ddots & \vdots \\ (1-\gamma_1)f_{n1} & \cdots & (1-\gamma_n)f_{nn} \end{bmatrix} \qquad [6.17]$$

The representation of expression [6.17] is reminiscent of an input-output table like [6.7]. We observe that the first matrix on the right hand side of equation [6.17] looks like a matrix of intermediate inputs, while the second matrix gives information on the corresponding real wage.

Clearly, the above gives a ‘bird’s eye view’ of the immediate post-disaster situation. Let us suppose now that the decision makers in the stricken area have access to this information. Given that, they immediately are confronted with the question how to proceed. If they have developed a set of appropriate scenarios, it is here that the rewards of having developed such a set will be seen. If there is no sense of where the economy should go now, an extremely confused situation will develop most likely. (This point will be addressed more fully later on). At the moment we shall assume that the decision has been made that the circular flow concept will form the basis for the reconstruction and recovery efforts. In that case, the next question is: which circular flow? The question apparently needs separate attention because up to now we only have defined a *circular flow in terms of a set of corresponding proportions*. In addition, as we may recall, we have introduced the notion of the existence of certain rigidities. Two of these are the characteristics of the real wage bundle and the role of employment policy. Below we shall assume therefore that the economy, in its immediate post-disaster period, focuses on restoring a circular flow *given* the presence of the signalled rigidities.

As a first step to further explore the character of [6.17], let us add the elements of $\underline{\mathbf{M}}_S$ row-wise, and adopt the symbol $\mathbf{t} = t_i$ for the vector of row-wise summed totals. This leads to the following equation:

$$\begin{bmatrix} (1-\gamma_1)z_{11} & \cdots & & (1-\gamma_n)z_{1n} \\ \vdots & \ddots & & \vdots \\ \vdots & & \ddots & \vdots \\ (1-\gamma_1)z_{n1} & \cdots & & (1-\gamma_n)z_{nn} \end{bmatrix} \begin{bmatrix} 1 \\ \vdots \\ \vdots \\ 1 \end{bmatrix} + \begin{bmatrix} \sum_i (1-\gamma_i) f_{1i} \\ \vdots \\ \sum_i (1-\gamma_i) f_{ni} \end{bmatrix} = \begin{bmatrix} t_1 \\ \vdots \\ \vdots \\ t_n \end{bmatrix} \qquad [6.18]$$

Equation [6.18] needs particular attention and will be discussed in the following Section. As we shall see, this expression ‘looks like’ an input-output system, but lacks the fundamental properties of an input-output system. However, it contains essential information for the economy on how to proceed.

6.4.1. Discussion of the After-Shock Equation

Although expression [6.18] may look like an input-output system in equilibrium, *it is not.* This is because it does not obey the fundamental input-output rules. We can see this immediately by calculating the implied input coefficients: dividing the elements of the i^{th} column of the matrix on the left-hand side by the corresponding t_i does not give us the correct pre-disaster intermediate input coefficients. We shall provide a simple numerical example in the next Section as an illustration of the argument. Apparently, in a very concise form, [6.18] expresses the disturbed proportions of the post-disaster situation when compared to the pre-disaster situation.

Essentially, equation [6.18] is only an identity in economic terms. This stems from its construction; the total ‘quasi-outputs’, the elements of **t**, on the right-hand side of expression [6.18] have been obtained by simple row-wise addition of the newly implied ‘intermediate’ and ‘final’ demands, and does not reflect existing economic possibilities. In this context, it may be useful to devote a few additional words to the character of the imbalances in the economy as reflected in [6.18]. So, let us take a look at the relation between the ‘intermediate’ and ‘final’ demands within identity [6.18]. In fact, standard, the total product of any industry is the sum of the two destinations – intermediate demand for inter-industry production inputs, and the final demand for final consumption purposes. We observe that proportions within the columns of the ‘intermediate part’ and within the ‘final’ demand vector have not changed. This is due to the fact that each column is multiplied by the same fraction $(1-\gamma_i)$, representing remaining capacity. Suppose, however, that we *actually* would like to interpret the first matrix on the left-hand-side as an intermediate input part in the input-output sense. It that case, the constructed 'vector of final demands' cannot be the corresponding final demand vector as the relationship between these two sets (of output destinations) is disturbed compared to the pre-disaster situation: the t_i's make no sense as sectoral totals as they are only mathematically obtained row sums. They cannot be interpreted as real industry output since the A-matrix coefficients cannot be recovered. Similarly, if we would like to interpret the other vector as a final demand vector in regular input-output sense, the intermediate input matrix would appear not to be the corresponding one, and again the t_i's would make no sense as totals. So, what we have here are, at best, *pieces* or *elements* of an input-output system, i.e. at best a part of a *potential* circular flow. The above notwithstanding, as we shall see, equation [6.18] gives extremely valuable information about the situation immediately after the disaster. In fact, it can be viewed as a very first effort at input-output accounting in the disaster's aftermath.

To express this, let us call expression [6.18] the *Basic equation*, thereby realizing that at the moment it is only an 'artificial' identity in a sense that it does not possess economic content yet, and thus cannot be interpreted in the standard input-output mode. In fact, the Basic equation is a mere snapshot of the immediate post-calamity disruptions and disorder in an economic system that used to be in balance, but is not anymore - and thus is (partially) inoperable. This system portrays disequilibrium in an input-output sense, having lost its internal consistency. This, in our view, forms stage one: *the basis for systematic accounting* for the actual physical damage brought about by a disaster. This means that at the moment we have a summary statement on what is left immediately after a catastrophe, and what is lost. This result is reflected in the type of 'artificial' accounts as [6.18].

Equation [6.18] also can be seen as a measure of the economic *vulnerability* of the system, because it shows in which degree a calamity will affect it in terms of loss of capacity. So, we need a second step to extract information regarding the economic structure from this 'artificial survey statement' and guide the economy to the equilibrium. Here, economic *resilience* gets a chance to be realised, i.e. how far a system is able to adjust to new circumstances, using even more limited resources than in a business-as-usual situation, and return to equilibrium with least costs, and as soon as possible. The third stage of disaster inquiry is the analysis of precautionary measures, which are indicative of *mitigation* and *adaptation* processes in anticipation of a potential danger. These are directed both at the limitation of a hazard, and at the improvement of the system's vitality, which concerns its resistance to major shocks, as well as its response capacity, resilience. Adjustments of an economic system in advance to a shock may result in changes in its structure, which means that both the pre-disaster equation, and the post-disaster identity (equations [3.1] through [3.8] and [6.1] through [6.18]) would change. This will ultimately affect the possible recovery paths as well as the final loss figures. In this way, one may compare the costs and benefits of various preventive measures, which is essentially a cost-benefit appraisal.

As we have discussed in Chapter 3, resilience is a relatively new concept to economic analysis, and it not an easy concept to measure without the presence of an actual shock. Spare production capacity present at individual production establishments, the presence of contingency plans, the availability of information, the coordination of actions and the technical solutions to the (temporary or permanent) breaks, are all indicative of the order of disaster preparedness and extent of resilience present in the system. (Studies on the nature and conceptualisation of resilience themselves should make another topic of a dissertation, as appears from the literature, which have proved time-intensive and lengthy projects.)

Many options become open for an economy in the disaster aftermath, restricted, however, by the available resources within the system. One of the opportunities is, as history often has shown, that as a result of a major calamity, such as a war, and the vast disruption following it, some countries are accepting the challenge of renovation, thereby adopting new technologies, while others opt to recover old ones. One of the instances was the renewal of the capital base in Germany after World War II, as opposed to the UK, where this was not the case. By 1970's it became apparent that renovation of capital stock had helped Germany to recover and to deliver a better economic performance, while British industry for a long time employed outdated machinery.

Uncertainty and complexity of the issues at hand suggest that the entire multitude of recovery paths can hardly to be analysed without policy directions or preferences. This is one of the core points governing scenario analysis, when extreme uncertainty about future developments of (often) one-time events is endogenised. Policy preference would then allow making particular assumptions about the desirable paths that an economy may be directed to, thus making the study more feasible and probably more realistic than a mere abstract theoretical exercise. Provided viable assumptions, a number of scenarios can be constructed to study, for example, best and worst cases without outside intervention in the markets, as well as government-steered recovery. Essentially, this brings us to the next modelling step, recovery modelling, which, however, will be first preceded by a numerical example illustrating the Basic equation.

6.4.2. The 'Basic Equation'; an Example

We shall illustrate the procedure described in the previous Section leading to the derivation of what we call the after-shock Basic equation by employing a numerical example of a two-sector two-commodity economy. (Later on, we shall also use a case study of a dike breach in the Netherlands to illustrate the use of our methodology on a more complicated example of a 38-sector input-output table).

Let us turn to our example, where we represent a stylised economy consisting of two sectors, agriculture and manufacturing. We start from the input coefficient matrix:

$$\mathbf{A} = \begin{pmatrix} 0{,}250 & 0{,}150 \\ 0{,}250 & 0{,}450 \end{pmatrix}$$

We assume that the final demand vector is:

$$\mathbf{f} = \begin{pmatrix} 150 \\ 450 \end{pmatrix}$$

This implies that the corresponding vector of total output is:

$$\mathbf{x} = \begin{pmatrix} 400 \\ 1000 \end{pmatrix}$$

The input-output system for our two-sector two-commodity economy results in the following expression in terms of coefficients:

$$\begin{pmatrix} 0{,}250 & 0{,}150 \\ 0{,}250 & 0{,}450 \end{pmatrix} \begin{pmatrix} 400 \\ 1000 \end{pmatrix} + \begin{pmatrix} 150 \\ 450 \end{pmatrix} = \begin{pmatrix} 400 \\ 1000 \end{pmatrix},$$

or, alternatively in absolute value terms:

$$\begin{pmatrix} 100 & 150 \\ 100 & 450 \end{pmatrix} \begin{pmatrix} 1 \\ 1 \end{pmatrix} + \begin{pmatrix} 150 \\ 450 \end{pmatrix} = \begin{pmatrix} 400 \\ 1000 \end{pmatrix}.$$

Straightforwardly, we now also have the intermediate input-output matrix **Z**:

$$\mathbf{Z} = \begin{pmatrix} 100 & 150 \\ 100 & 450 \end{pmatrix}$$

Following the discussion in the previous Section, we explicitly distinguish only one primary factor, labour. Above, the corresponding labour input coefficients are given by:

$$\mathbf{l} = \begin{pmatrix} 0{,}500 & 0{,}400 \end{pmatrix}$$

We observe that the value of total labour income, *L*, is 600, which equals the total value of final demand (150+450). The values of wages paid per sector are thus for agriculture 400·0,5 = 200, and for manufacturing sector 1000·0,4 = 400. Provided knowledge of *L* and **l**, we can arrive at matrix **F**, representing the real wage part expressed as bundles of consumed goods (following the transformation as in [6.9]):

$$\mathbf{F} = \begin{pmatrix} 50 & 100 \\ 150 & 300 \end{pmatrix}$$

To complete our transformation, we are constructing the matrix $\underline{\mathbf{M}}$ as in [6.7] to have the representation of the pre-disaster economy in nominal money terms, divided into two matrices reflecting respectively the bundles of intermediate production demand and final consumption.

$$\underline{\mathbf{M}} = \begin{pmatrix} 150 & 250 \\ 250 & 750 \end{pmatrix} = \begin{pmatrix} 100 & 150 \\ 100 & 450 \end{pmatrix} + \begin{pmatrix} 50 & 100 \\ 150 & 300 \end{pmatrix}$$

Let us assume now that a disaster hits, and destroys agriculture more heavily than manufacturing. For example, the ‘disaster parameters’, derived from the knowledge on the location of the destroyed activities and their production value, are $\gamma_1 = 0{,}40$ for agriculture and $\gamma_2 = 0{,}20$ for manufacturing. So, similarly as in [6.15] we may write:

$$\underline{\mathbf{M}} = \left[\left\{ 0{,}4 \left[\begin{pmatrix} 100 \\ 100 \end{pmatrix} + \begin{pmatrix} 50 \\ 150 \end{pmatrix} \right] + 0{,}6 \left[\begin{pmatrix} 100 \\ 100 \end{pmatrix} + \begin{pmatrix} 50 \\ 150 \end{pmatrix} \right] \right\} \right.$$

$$\left. \left\{ 0{,}2 \left[\begin{pmatrix} 150 \\ 450 \end{pmatrix} + \begin{pmatrix} 100 \\ 300 \end{pmatrix} \right] + 0{,}8 \left[\begin{pmatrix} 150 \\ 450 \end{pmatrix} + \begin{pmatrix} 100 \\ 300 \end{pmatrix} \right] \right\} \right]$$

Reassembling terms of the above $\underline{\mathbf{M}}$ matrix, and separating the survived part, we obtain the following identity for the matrix describing the surviving capacity, consisting of intermediate and final demand categories:

$$\underline{\mathbf{M}}_S = \left(0{,}6 \begin{bmatrix} 100 \\ 100 \end{bmatrix} \quad 0{,}8 \begin{bmatrix} 150 \\ 450 \end{bmatrix} \right) + \left(0{,}6 \begin{bmatrix} 50 \\ 150 \end{bmatrix} \quad 0{,}8 \begin{bmatrix} 100 \\ 300 \end{bmatrix} \right)$$

or:

$$\underline{\mathbf{M}}_S = \begin{pmatrix} 60 & 120 \\ 60 & 360 \end{pmatrix} + \begin{pmatrix} 30 & 80 \\ 90 & 240 \end{pmatrix} = \begin{pmatrix} 90 & 200 \\ 150 & 600 \end{pmatrix}$$

So, we have illustrated how the productive capacity can be split into two parts in a consistent way within an input-output framework, based on the knowledge of physical disruptions. The part of the system that survived the disaster now can be written in the form of the post-disaster Basic equation [6.18], as:

$$\begin{array}{ccccccc} \text{Intermediate Input Active} & & & \text{Final Demand Active} & & \text{Total Output Active} & \\ \begin{pmatrix} 60 & 120 \\ 60 & 360 \end{pmatrix} & \begin{pmatrix} 1 \\ 1 \end{pmatrix} & + & \begin{pmatrix} 110 \\ 330 \end{pmatrix} & = & \begin{pmatrix} 290 \\ 750 \end{pmatrix} & \qquad [6.19] \end{array}$$

Looking at [6.19] we can make a number of observations. First, we immediately notice that the agricultural sector has become significantly smaller compared to manufacturing. In fact, the whole system has shrunk, but not proportionally. Our second observation is that the internal relations are disturbed between the intermediate and final demand, which raises the question whether the available intermediate inputs would be enough to produce goods for the required final demand. Next, ‘the vector of the total output’ on the right hand side of the identity has been obtained by adding up the elements row wise, but as we know, this is by pure construction; there is no economic content. Essentially, it is questionable whether the survived intermediate part is able to satisfy final demand as presented in [6.19], and whether the amount of produced goods would add up to the induced total as it stands in [6.19].

Equation [6.19] also points to the fact that many things are uncertain. Some of these are not difficult to see. It is a big question, for example, whether the structure of final demand would remain the same, or would tend to change, say, in favour of agricultural products as the basic needs in nutrition should be satisfied first in a situation of limited resources. A further big question is, alternatively, whether the need for manufactured goods would be a dominating factor in view of the reconstruction. In the next Section we shall discuss further recovery challenges and possibilities. Ultimately, it is important to know which options are available, to compare them, and to see which ones are desirable.

6.5. THE ROLE OF PROPORTIONS IN RECOVERY PLANNING

At this point we need to 'take stock', and reflect for a moment on the structure the disaster has left behind – as presented in [6.18]. The spared area now faces the task to reassemble these parts, and to rebuild the system based on what is left. Below we shall present a procedure on how to recombine what is left *with a specific goal in mind*. This goal is, as we already mentioned it, to construct or, better perhaps, *to reconstruct an economy based on the circular flow notion*. At the same time, we shall recognize the existence of, in particular, two types of rigidities. One is connected to the role of technology. The other one concerns the most important role of employment goals in our industrialized societies; to which final households' demand vector with its established proportions is directly connected. We shall start with a graphical exposition, first based on Dorfman, Solow and Samuelson (DOSSO, 1958). Hereafter we shall present a method of our own.

The first graphical representation, Figure 6.3, is adopted from DOSSO (*ibid*). First we shall show how the equilibrium embodied in the equations ([3.1], [3.2]) can be depicted graphically. To this end, let us again consider a two-sector economy in familiar notation. We have the real system:

$$\begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}\begin{pmatrix} x_1 \\ x_2 \end{pmatrix}+\begin{pmatrix} f_1 \\ f_2 \end{pmatrix}=\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \qquad [6.20]$$

and the accompanying labour equation:

$$l_1 x_1 + l_2 x_2 = L \qquad [6.21]$$

We rewrite to obtain three equations:

$$\begin{cases} (1) & (1 - a_{11})x_1 - a_{12}\, x_2 & = & f_1 \\ (2) & -a_{21}\, x_1 + (1 - a_{22})x_2 & = & f_2 \\ (3) & l_1\, x_1 + l_2\, x_2 & = & L \end{cases} \qquad [6.22]$$

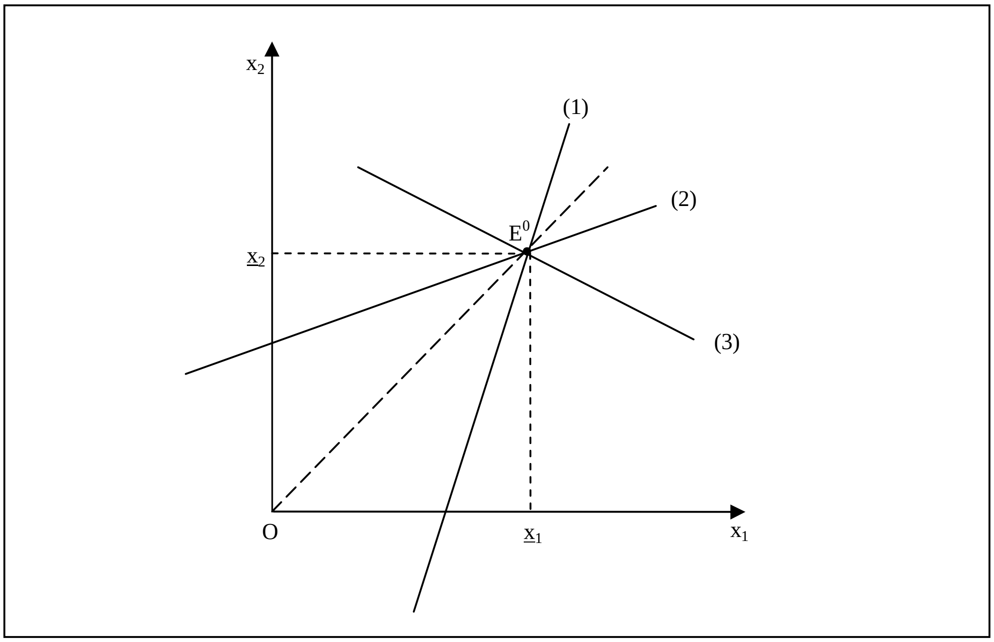

Figure 6.3. *Graphical representation of the total output of an open input-output system.*

For given values of **f**, say **f̲**, we may represent system [6.22] graphically as in Figure 6.3, where the numbers representing the lines correspond to the equations as given above. Let **x̲** = ($\underline{x}_1$, $\underline{x}_2$) represent the solution to [6.22], graphically represented by point E^0. The lines (1), (2) and (3) intersecting at point E^0 represent the equations of the system [6.22].

6.5.1. Modelling Recovery: A Different Representation

It is not well known that we can depict the same input-output system in an alternative way. Let E^0 again denote the vector of total outputs **x̲**.[65] Let furthermore $\overrightarrow{OQ}^0$ stand for the vector of total intermediate inputs **Ax̲**, and $\overrightarrow{OF}^0$ for the vector **f̲**. We now have, in vector notation (see Figure 6.4), $\overrightarrow{OQ}^0$ and $\overrightarrow{OF}^0$ representing the intermediate and final demand vectors, and $\overrightarrow{OE}^0$ the vector of total output. We can also write:

$$\overrightarrow{OE}^0 = \overrightarrow{OQ}^0 + \overrightarrow{OF}^0 \qquad [6.23]$$

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[65] Note that Figures 6.4 through 6.10 are drawn on a scale different from Figure 6.3.

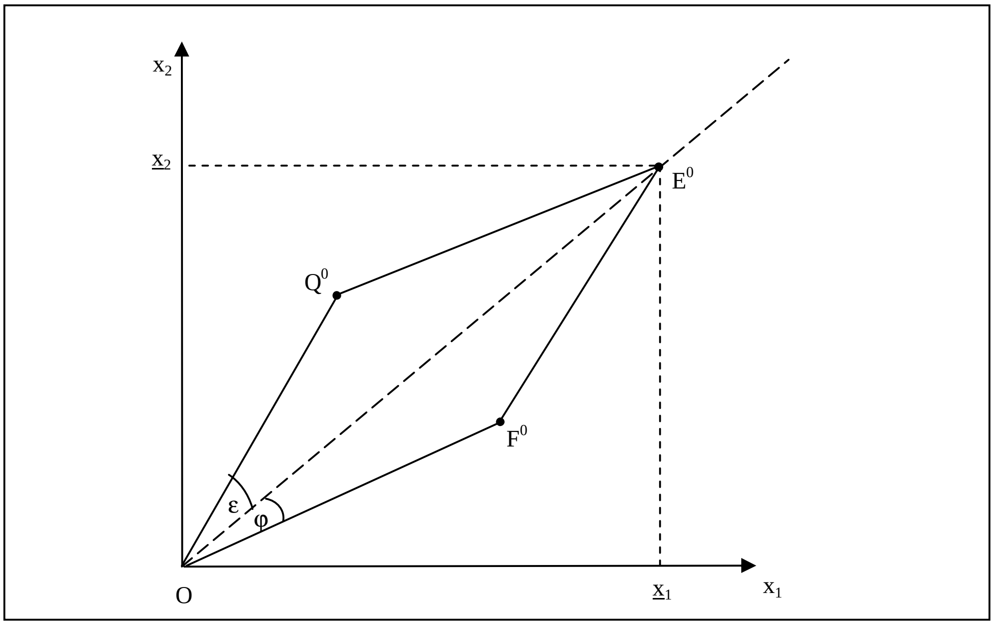

Figure 6.4. *Output as addition of intermediate and final demand vectors in an input-output system.*

That is, our equilibrium now is represented in terms of vector addition, with the points Q^0 and F^0 on either side of the ray OE^0. We should observe the angles Q^0OE^0 and E^0OF^0, in Figure 6.4 denoted by the symbols ε and φ, respectively. They embody our knowledge of the production technologies as given by the columns of matrix **A**.

Let us assume now that a disturbance of the internal circular flow is takes place. To explore its effects, we shall start with a *homogeneous* disturbance or shock. Figure 6.5 depicts, also in vector addition format, an 'imploded' economy in point E^1 that has maintained the same proportions as our initial economy in point E^0. We now define the shock in terms of the following proportional decline, where the superfix '1' refers to the post-disaster situation:

$$\frac{OE^1}{OE^0} = \frac{OQ^1}{OQ^0} = \frac{OF^1}{OF^0} = \lambda < 1 \qquad [6.24]$$

That is, total outputs, intermediate inputs and final demand have decreased in the same proportions. Here, again, it holds true that the new vector of total outputs $\overline{OE}^1$ equals the sum of the new intermediate demands, $\overline{OQ}^1$, and final demand, $\overline{OF}^1$:

$$\overrightarrow{OE}^1 = \overrightarrow{OQ}^1 + \overrightarrow{OF}^1 \qquad [6.25]$$

We observe that in this case the angles Q^0OE^0 and E^0OF^0 also are equal to ε and φ, as introduced earlier.

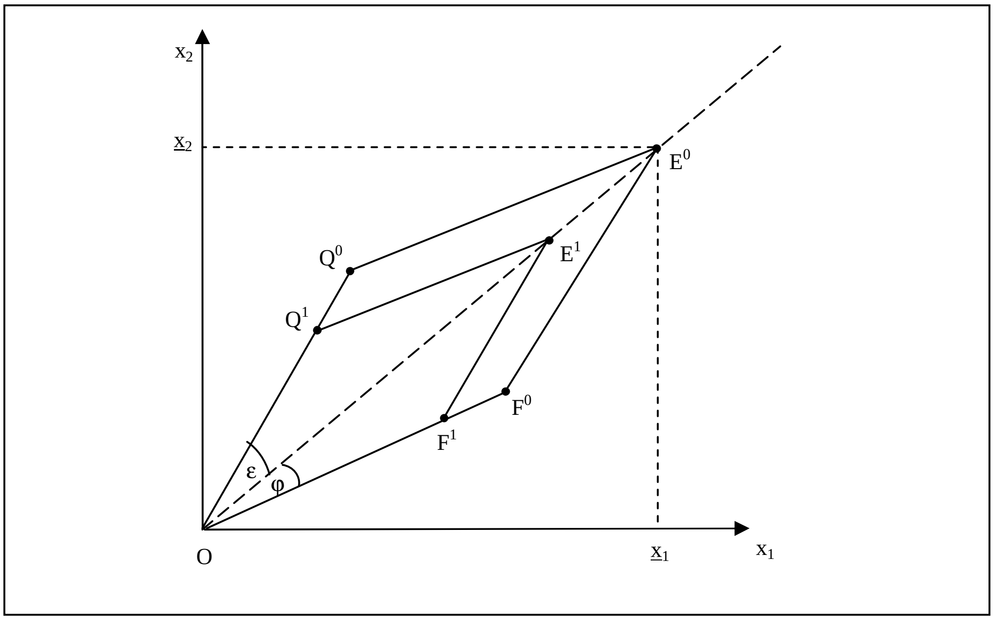

Figure 6.5. A homogeneous shock in an input-output system.

Now, let us consider the impact of a big disaster, with characteristically *non-homogeneously* disturbed internal proportions. We then return to the Basic equation [6.18] that we have derived in Section 6.4. Let us now denote, for our two-sector economy, the point E^2 as corresponding to the vector **t**, obtained via row-wise addition as described earlier (see Section 6.4.1). We reflect it on Figure 6.6 below.

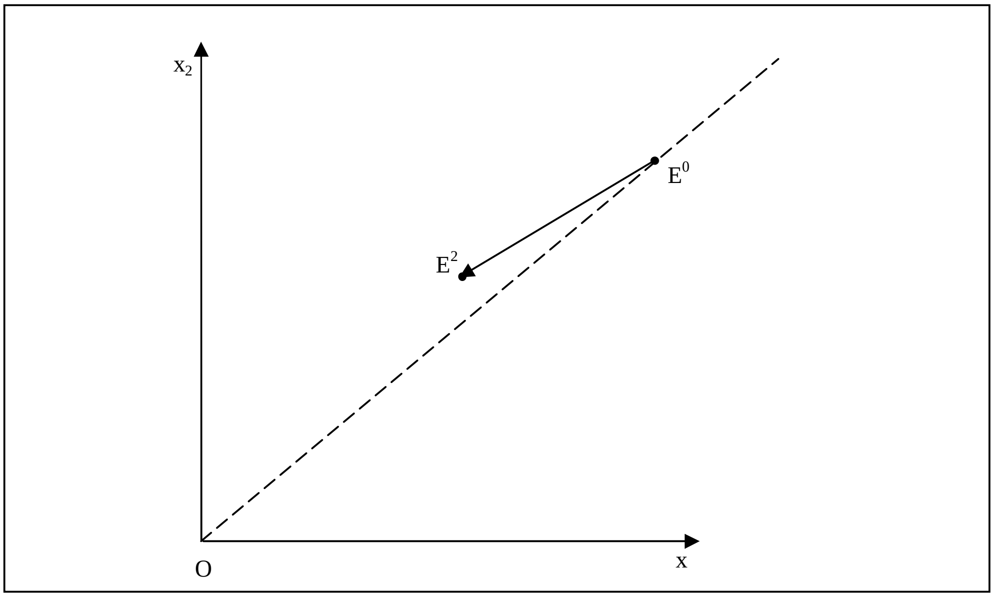

Figure 6.6. A heterogeneous shock in an input-output system.

Earlier we have observed that the vector of ‘quasi final demand’, $\tilde{\mathbf{f}}$, in our Basic equation [6.18] is proportional to **f** in equation [3.1]. However, as we have seen, for the point E^2 to be interpreted as the total output vector of a system producing a net output equal or proportional to **f**, it should lie on the ray OE^0. Because it does not (due to our assumption of the non-homogeneous shock), we can be sure that the bundle of goods $\tilde{\mathbf{f}}$ cannot be produced by the post-disaster economy in a circular flow configuration. This thus means that the vector addition

$$\overrightarrow{OQ}^{2} + \overrightarrow{OF}^{2} = \overrightarrow{OE}^{2} \qquad [6.26]$$

cannot be interpreted as an input-output system. Figure 6.7 is representative of the situation. Note that we have a new angle Q^2OE^0 that we denote as δ, with $\delta \neq \varepsilon$. At the same time, the angle φ is unchanged relatively to the pre-disaster ray OE^0, signalling that vector $\tilde{\mathbf{f}}$ is proportional to **f**. So, because the proportions between final consumption and intermediate inputs are distorted, we can say that the economic structure described by the point E^2 is not a balanced system, and has to look for a new equilibrium. This is precisely what the Basic equation [6.18] tells us. However, it is a most useful starting point for finding a real working system that is ‘embedded’ in the equation [6.18] - in fact, we are allowed to speak of an ‘extraction’ process.

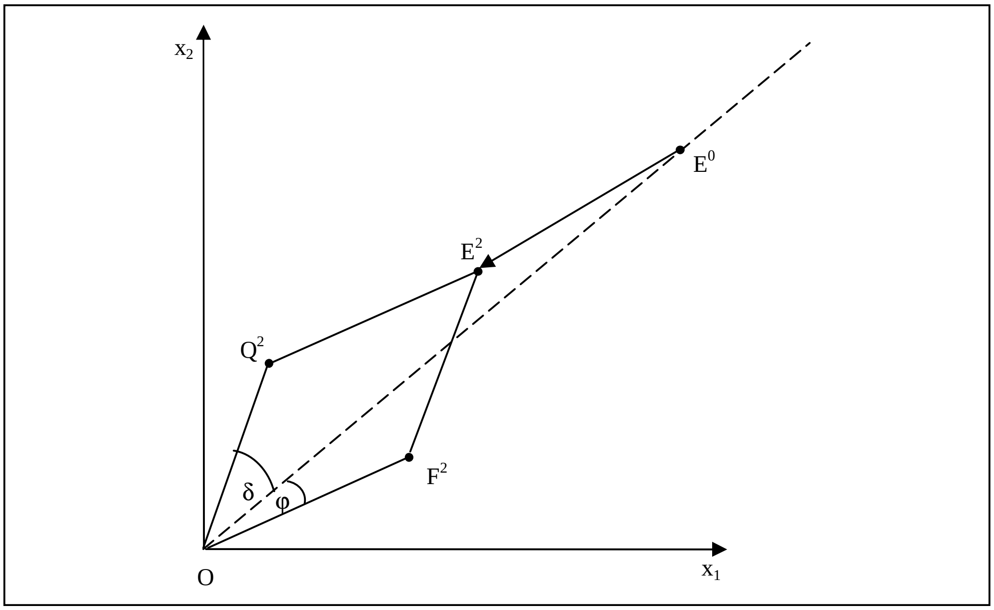

Figure 6.7. *Graphical representation of the Basic equation.*

The recovery process requires *a vision* of where the economy is to go. Without a clear idea where post-disaster recovery efforts should be directed at, a ‘laissez-faire’ recovery will not necessarily result in a socially acceptable outcome. In case the decision is taken to centrally steer the recovery, the government should have a particular goal in mind with a corresponding set of strategies for the post-disaster reconstruction period. Essentially, the task ahead for the country is to agree on such balances, and to devise a transition path to reach them. Our approach now will be to 'use' equation [6.18] to arrive at internally consistent balances. Clearly, many possibilities exist here. We already mentioned that the country may wish to 'use the occasion' to diversify or modernise its production facilities. Alternatively, it may also opt for integrating its economy better in existing national or international cooperation schemes or, rather, for becoming less dependent on particular sources or connections by investing in selected sectors. Here the post-disaster Basic equation can be most helpful for structuring the recovery decisions and determining the desired internal and external balances for a particular direction.

Some authors pointed at a path that leads to restoration of the pre-catastrophe proportions. To quote Tobin, for example, (1999, p.15): "For instance, many relief programmes strive to return communities to the *status quo ante*, indeed, a common refrain from victims and politicians alike following a disaster is 'to get back to normal'." He adds (*ibid*), "… to understand recovery, attention must be focused on: 1) re-accumulation of capital and physical infrastructure; 2) policies and programmes of government agencies, private organisations, and businesses among others; 3) resource distribution."

The above also leads to accompanying notions of what actually has been lost in the disaster, and the type of costs the post-catastrophe country faces. Many possibilities exist here, evidently. We shall concentrate on one particular option, i.e. the case where one wishes to define the total cost of the disaster as the costs made to return to the position where the economy would have been if the disaster had not happened; where the initial position (before the catastrophe) acts as a basic reference point. A similar view can be found in (Bram, Orr and Rapaport, 2002), where the effects of the 9-11 attacks are studied on the development of employment in New York city via comparing factual trends with counterfactual inference in the trend had there been no attack. Such a look at the definition of disaster-imposed costs, in fact, means that these costs will depend on the speed of an economic system to return to the pre-disaster track.

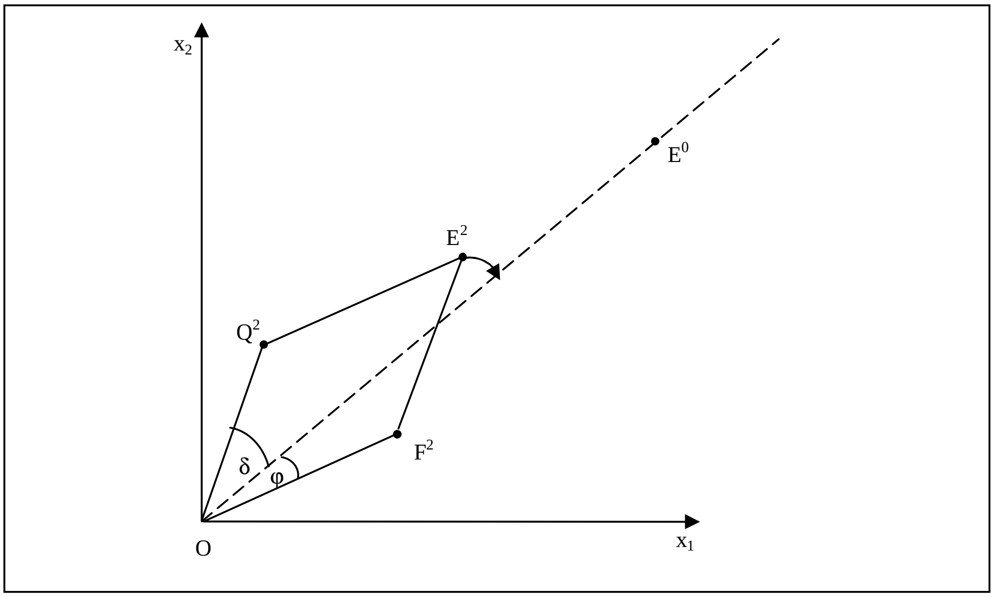

Figure 6.8. *Defining the recovery strategy.*

This implies, in turn, that the goals chosen, and, consequently, the recovery path followed, will affect the total figure of disaster losses. In this sense, to keep the costs as low as possible, one needs to select a 'fastest', i.e. a most 'effective' recovery strategy. This resembles the turnpike idea, to which we shall return later in this Section.

First, we shall pay attention to one option especially. That is, as mentioned, we shall suppose that the post-disaster economy wishes to return to its *pre-disaster proportions* as depicted by the ray OE^0 in Figure 6.8. The consequence of this choice is that total inputs and final demand should be proportional to total inputs and final demand as required by the economy in point E^0.

Starting from E^2, how could we 'move' to E^0? First of all, we may notice from Figure 6.8, that E^2 can be reproduced as the summation of the vectors $\overrightarrow{OQ}^2$ and $\overrightarrow{OF}^2$. Furthermore, we know that the intermediate inputs are 'out of proportion' relative to the pre-disaster situation (as the angle δ is different from the initial angle ε), and that the relative magnitudes are not the correct ones. This means that to arrive at some new equilibrium on the ray OE^0, we need to 'correct' only the proportions of intermediate consumption. If reaching this goal has succeeded, and our new intermediate input demand has the same relative proportions as OQ^0 (see Figures 6.4 and 6.5), then the summation of the vectors of intermediate and final consumption should result in a total output on the desired ray OE^0. We shall review two manners how this can be achieved.

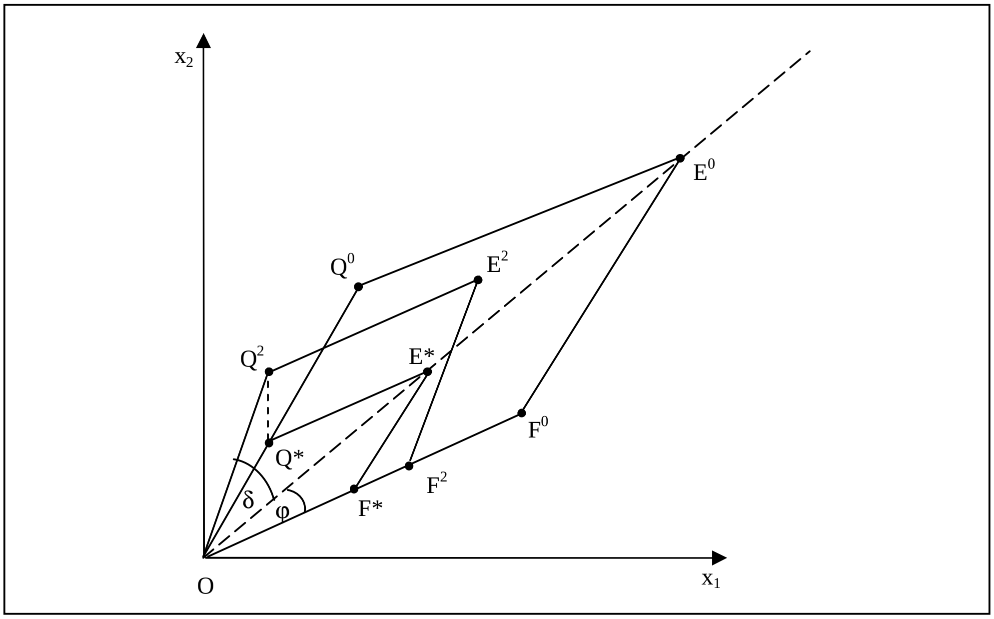

Figure 6.9. *The recovery strategy: an extreme case of returning to pre-disaster proportions*

First, consider a solution as illustrated in Figure 6.9. In the post-disaster situation good 2 is present in relative abundance compared to good 1, i.e., it is in excess supply (in other words, essentially, good 1 is a bottleneck to recovery as it is relatively scarce). Given the proportion requirement for the production of goods dictated by the prevailing technologies, a part of the total amount of good 2 becomes 'idle' and has to 'drop out' of the system (i.e., the intermediate product mix will shift from OQ^2 to OQ^*). Several options are open regarding this quantity of good 2. For example, it possibly may be sold to agents outside the intermediate modelling context as part of exports; yet, *in the short run*, when *inter alia* institutional rigidities prevail (as we discussed in Chapter 3), this is unlikely. After the catastrophe, communication channels may be out of order, roads may be blocked or displaced, information is incomplete, and financial resources are limited. So, for the immediate disaster aftermath, we shall assume that the availability of all resources is *fixed*, and that good 2 cannot be used for alternative purposes; so, it becomes a loss. This means that the economy will start growing again from the point E*, where the circular flow is restored. Yet, we should notice, that this is an extreme contraction, which requires final consumption to reduce for a while to the level of OF* (see Figure 6.9).

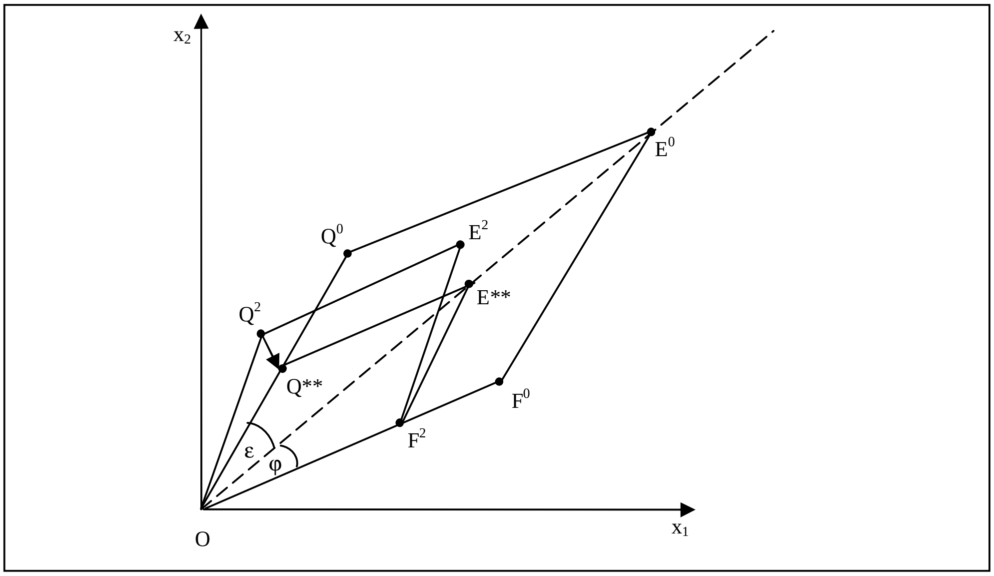

Figure 6.10. *The recovery strategy: 'correction' of proportions in intermediate transactions*

There is yet another option for restoring pre-disaster proportions (see Figure 6.10). We may start from the final demand requirement that we have obtained from our immediate post-disaster accounts, the Basic equation [6.18]. The government may decide to aim at favouring the final consumption at the highest possible level, i.e. at the level of OF^2. Given this goal, a solution to the associated input-output equation will provide the corresponding total output and the intermediate input requirements (we need make sure that the 'right' technologies are used). Following this procedure, we shall end up with the vector of intermediate inputs OQ^{**} (on the OQ^0 ray, see Figure 6.10), where the post-disaster circular flow, and thus equilibrium, will be restored as given by the point E**. The question here is: are there enough production capacities to satisfy this final demand? Possibly, this road can be followed when resource mobility is again possible, and extra capacities in the needy sectors can be acquired 'in exchange' for production from the less affected sectors.

6.5.2. Initial Position and Recovery; an Example

Now let us return to our stylised example. In Section 6.4.2 we have derived the post-disaster basic equation [6.19] for the case of a 2x2 stylised example. We shall repeat it here as a starting point for our recovery analysis:

$$\begin{pmatrix} 60 & 120 \\ 60 & 360 \end{pmatrix} \begin{pmatrix} 1 \\ 1 \end{pmatrix} + \begin{pmatrix} 110 \\ 330 \end{pmatrix} = \begin{pmatrix} 290 \\ 750 \end{pmatrix} \qquad [6.19]$$

In the immediate disaster aftermath, all we have is this identity [6.19]; we have pointed out that although in a basic equation such as [6.19] we have a representation of the survived part of an economy, there is yet no balance. To illustrate that, we rewrite the identity in the form of the 'induced' input-output equation, obtained by dividing the column elements by the corresponding row totals:

$$\begin{pmatrix} 0,207 & 0,160 \\ 0,207 & 0,480 \end{pmatrix} \begin{pmatrix} 290 \\ 750 \end{pmatrix} + \begin{pmatrix} 110 \\ 330 \end{pmatrix} = \begin{pmatrix} 290 \\ 750 \end{pmatrix}$$

It becomes clear that the technologies are not the 'correct' ones; the production coefficients have changed. Thus, the Basic equation presupposes technologies different from those present 'in reality'. We now shall rewrite the equation in terms of the 'correct' (pre-disaster) input coefficients. We obtain:

$$\begin{pmatrix} 0,250 & 0,150 \\ 0,250 & 0,450 \end{pmatrix} \begin{pmatrix} 240 \\ 800 \end{pmatrix} + \begin{pmatrix} 110 \\ 330 \end{pmatrix} = \begin{pmatrix} 290 \\ 750 \end{pmatrix}$$

The above equation, however, is an 'impossible' input-output system. The output vector on the left hand side of the equation above is not equal to the total obtained from the Basic equation, on its right hand side. Moreover, we directly observe that this economy *cannot* provide the real wage bundle for its workers. Calculation suggests that an economy which produces total outputs of 240 units of agricultural goods and 800 of manufacturing goods only can produce a net output bundle of 60 units of food and 380 of manufacturing, as given by the following input-output equation:

$$\begin{pmatrix} 0,250 & 0,150 \\ 0,250 & 0,450 \end{pmatrix} \begin{pmatrix} 240 \\ 800 \end{pmatrix} + \begin{pmatrix} 60 \\ 380 \end{pmatrix} = \begin{pmatrix} 240 \\ 800 \end{pmatrix}$$

The explanation is straightforward; provided no technological change is present or possible, we are faced with a disproportion between the intermediate inputs part and final demand (which in our case is the workers' real wage). So, does it actually represent an operable circular flow? Clearly, policy-makers must decide on finding a strategy for reaching the OE^0 ray. Several options are open. Let us mention two straightforward ones.

First, let us start with an illustration of a possible transition to the E^0 path based on Figure 6.9. As we mentioned before, this is a rather extreme case. Let's take again a look at the proportions. The initial pre-calamity total output proportions of the OE^0 ray (see Section 6.4.2) are 400:1000=0,4; and the proportions of final demand OF^0 are 150:450=0,333. In the post-disaster system described by the last equation above, total output proportions are 240:800=0,3; and final demand proportions are 60:380=158. From this, we can derive that, comparing to the pre-disaster 'trend', good 2 now is present in relative abundance to good 1. So, 'correcting' the final demand and total output proportions in the system above, we arrive at the following input-output system:

$$\begin{pmatrix} 0,250 & 0,150 \\ 0,250 & 0,450 \end{pmatrix} \begin{pmatrix} 240 \\ 600 \end{pmatrix} + \begin{pmatrix} 90 \\ 270 \end{pmatrix} = \begin{pmatrix} 240 \\ 600 \end{pmatrix} \qquad [6.27a]$$

The equation [6.20a] above represents an operable circular flow, in the sense that we may interpret it in terms of 'good' balances and proportions. We may observe, that such a system with a total output of (240, 600) is able to produce final demand in the required proportions at the level of (90, 270). This is clearly lower than the economy's potential described by the post-disaster equation [6.19], which also corresponds to the situation E* in Figure 6.9 as we described in the previous Section. This means that an 'additional' (indirect) loss of 200 units (which is obtained as a difference (290+750)-(240+600)) should be accounted for, mounting to the total loss of 560 units at this point in time, which is 40% of the initial production capacity. This is, in fact a proportional implosion of an economy provided the level of a maximum disruption coefficient (recall that we assumed $\gamma_1 = 0{,}40$ and $\gamma_2 = 0{,}20$).

We have also considered another possibility for recovery, namely, that we start from the Basic equation (such as [6.19]), and try to obtain the desired proportions, following the procedure corresponding to Figure 6.10. In fact, if we look at the Basic equation, we see that final demand proportions correspond to those in the pre-disaster situation. What is 'wrong' with a system like [6.19], is the proportions between the total output. So, to 'correct' those, we would need the combination of (290, 725) instead of (290, 750), which we have in [6.19]. This means, that then we have a system like:

$$\begin{pmatrix} 0,250 & 0,150 \\ 0,250 & 0,450 \end{pmatrix} \begin{pmatrix} 290 \\ 725 \end{pmatrix} + \begin{pmatrix} 110 \\ 330 \end{pmatrix} = \begin{pmatrix} 290 \\ 725 \end{pmatrix} \qquad [6.27b]$$

The system [6.20b] also has 'good' proportions, just as system [6.27a]. Yet, the difference is that in the situation described by equation [6.27b], the corresponding interindustry transactions matrix would look like:

$$\begin{pmatrix} 73 & 107 \\ 73 & 322 \end{pmatrix}.$$

To clarify, the respective inter-industry transactions matrix for equation [6.20a] would coincide with the one in the Basic equation [6.19]. Comparing the two matrices, we can see that in the latter case, where we kept final demand at its maximum requirement level (110, 330), we would need a situation, where sector 1 would need some extra production capacity that is directly available in the immediate disaster aftermath. This means, that the latter solution would not be possible at the moment when rigidities manifest themselves; this is rather a solution to be pursued when resource re-allocation is possible.[66] The total loss incurred by a disaster to the production capacity of a country in this case (and at this stage) will be 27,5%.

Besides the issue of obtaining the 'right' proportions and looking for a new equilibrium, we observe, naturally, that once the economy has reached the (desired) OE^0 ray, it still faces the problem of having to develop a growth program (e.g., such as to reach its pre-disaster position at $E^{0,}$ and possibly to expand beyond). In terms of our model this means e.g. that part of final demand in [3.1] now must be set aside for capital construction to facilitate expansion. This, however, is the domain of dynamic Leontief theory, and will not be pursued here (see Section 5.3, Chapter 5 for the basic description of a dynamic model). Also, we may observe a connection with standard turnpike theory.[67] Regarding this, we should remark that application would not be straightforward, present insight in the properties of the dynamic versions of the Leontief model (especially regarding the role of stability issues) is still not sufficiently developed.[68]

Finally, we hope to have shown the importance of being prepared in the sense of having available a set of scenarios for the post-disaster period. As we have seen, there exist many ways for an economy to react. Most important in our notion of recovery is the notion of proportions and balances, which should be sought in a structured manner.

6.6. THE BASIC EQUATION: AN ALTERNATIVE DERIVATION

As we have discussed earlier in Chapter 6, because a substantial part of productive capacity is gone, the catastrophe may be expected to generate a *multitude* of *imbalances* or *disproportions* in the economy's supply-demand relations. Below we shall return to some of these, and try to systematize the post-disaster imbalances in a way alternative to what we have presented in Section 6.4. Our goal remains the same, i.e. to determine the nature and origin of disaster implied disruptions in its immediate aftermath. This alternative approach also makes use of precise knowledge of the geographical dimension involved.

Below we shall again concentrate on the concept of a *circular flow* as providing the underlying fundamental structure for research on catastrophes. As before, we shall discuss the circular flow in terms of a set of inputs, which matches, given certain technologically determined parameters, a set of outputs which subsequently becomes a

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[66] Yet, in a situation like above, where we have tacitly assumed that the desired quantities of both goods could be sold or bought at the appropriate markets, we directly face the limits of our model, which basically is 'inward-looking'. To address questions like these sell or buy decisions, a more extended model is needed that incorporates relations with the outside world.

[67] Turnpike theory is based on the idea that optimality in growth paths in many cases depends on a 'closeness' to certain special growth or development trajectories, such as von Neumann's balanced or proportional growth path. See e.g. Tsukui and Murakami (1972).

[68] For a recent contribution and an explanation of certain instability problems, see Steenge and Thissen (2005).

set of inputs in the next round. This notion provides part of the necessary background for terms like 'imbalances' or 'disproportions'. The next question then, clearly, is: in relation to precisely which aspect (or aspects) of a circular flow do we use these terms?

Evidently, the notion of circularity, in the somewhat sketchy form as given above, needs precision. In fact, we need some kind of 'anchor' to proceed sensibly. In our case, this anchor is provided by the notion of the consumption bundle **f** as introduced in Chapter 3. This bundle is the exogenously determined and fixed set of consumption goods bought and consumed by each consumer. Because of the one-to-one relation between consumers and workers that we have imposed, this bundle also stands for the real wage. As signalled earlier above, many recovery paths exist. However we will select one where the pre-disaster composition of final demand will provide the required anchor. In terms of our model, this means that given **f**, we directly know which total output vector **x** is involved; the level of **f** determines the level of **x**. A different composition of **f** implies a different **x**. However, we shall concentrate on the case of a final demand vector of with the mentioned characteristics.

In Sections 6.3-6.5, we introduced the disaster-adapted presentation of the basic model ([3.1], [3.2]), employing the notion of the real wage bundle. However, there is a alternative way of thinking about the transition from the pre-disaster to the post-disaster situation. We have, by assumption, discarded any possible changes in **f** following the catastrophe. So, this source of possible adaptation is excluded. Similarly, we have assumed that in the immediate post-disaster period, the adoption of alternative technologies (which possibly may be more 'appropriate' under the new circumstances than the ones in place) also is precluded. We thus can view the economy in terms of a set of interrelated *fixed* technologies.

Here we reach an important point: once the consumption vector is known (relative or absolute), we also know the proportions in which the other activities *should* be combined. This has a direct consequence: suppose all activities except one satisfy these proportions. If the one activity that does 'not fit' has a lower output than 'prescribed' by the required proportions, it immediately becomes the production bottleneck, and effectively determines the scale in which the entire economy can operate. This is an immediate consequence of the limitational character of the Leontief production processes (i.e. there are no substitutes available).

This recalls the opinion voiced by Schlesinger and Zeuthen, as referred to in Chapter 1. Economists tend to focus too much on equilibrium situations with supply-demand equalities. Much of reality, however, is concerned with a different question, i.e. which activities are in oversupply and which in undersupply, and how does that influence prices? So, we are faced with *this* particular question, against the background of a very specific and well-defined output task, i.e. finding a path that corresponds to the production of workers' consumption in the proportion of **f**.

In this context, a different type of multi-sector model seems worthwhile to explore. First of all, we now are thinking of a *closed* model. Open input-output models are characterised by the fact that the primary factors form a different category in the sense that their provision usually is not part of the analysis. Correspondingly, if they are in excess supply, their removal from the system does not cause any problem. In a closed model, our (single) primary factor, i.e. labour, is treated as an *input* into a process that generates labour power. As we shall see, in this reformulated model availability issues (of goods and commodities) can be interpreted and discussed in a way reminiscent of Von Neumann's economic system (Von Neumann, 1945/46).

Here we aim to describe the situation right after the shock when the economy has not yet adapted to the new situation. As in Chapter 6, we shall start from the standard open model. We recall equations [3.1] and [3.2] from the earlier formulation:

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{f} \qquad [3.1]$$

$$L = \mathbf{l}\mathbf{x} \qquad [3.2]$$

We can rearrange the above equations as a closed input-output system, including intermediate inputs *and* the previously primary production factor, labour. Labour now explicitly is modelled as an *input*:

$$\left[\begin{array}{c:c} \mathbf{A} & \left(\frac{1}{L}\right)\mathbf{f} \\ \hdashline \mathbf{l} & 0 \end{array}\right] \left[\begin{array}{c} \mathbf{x} \\ \hdashline L \end{array}\right] = \left[\begin{array}{c} \mathbf{x} \\ \hdashline L \end{array}\right] \qquad [6.28]$$

or

$$\left[\begin{array}{c:c} \mathbf{A} & \mathbf{h} \\ \hdashline \mathbf{l} & 0 \end{array}\right] \left[\begin{array}{c} \mathbf{x} \\ \hdashline L \end{array}\right] = \left[\begin{array}{c} \mathbf{x} \\ \hdashline L \end{array}\right] \qquad [6.28a]$$

Where again

$$\mathbf{h} \equiv \left(\frac{1}{L}\right)\mathbf{f} \qquad [6.1]$$

Introducing matrix $\breve{\mathbf{M}}$ (note that by construction it is different from matrix **M** introduced in equation [6.4], Section 6.3.):

$$\breve{\mathbf{M}} \equiv \left[\begin{array}{c:c} \mathbf{A} & \mathbf{h} \\ \hdashline \mathbf{l} & 0 \end{array}\right] \qquad [6.29]$$

and the column vector **q** of production intensities where:

$$\mathbf{q} \equiv \left[\begin{array}{c} \mathbf{x} \\ \hdashline L \end{array}\right] \qquad [6.30]$$

we obtain

$$\breve{\mathbf{M}}\,\mathbf{q} = \mathbf{q} \qquad [6.31]$$

That is, we have moved from a formulation in terms of an open Leontief model to a formulation in terms of a *closed* Leontief model, including an equation for the previously primary factor, labour. Consequently, the dimensions of the system matrix now have become (n+1) x (n+1). We should observe that this model is different from the standard closed model as discussed in, e.g., Pasinetti (1977). In that model, the fixed coefficients assumption applies to all industries, including households. In [6.29], however, this assumption only applies to the sub-matrices **A** and **l**. If the consumption preferences as registered in **f** change (for example, when we discuss the possibilities for a cost-benefit analysis in Section 3.8), also **x** and L change correspondingly to new values $\tilde{\mathbf{x}}$ and $\tilde{L}$, and we will have a new column vector $\tilde{\mathbf{h}}$ which replaces **h** in the matrix on the left hand side of [6.28a]. We see that the eigenvector equation [6.31] describes an economy in perfect equilibrium: $\breve{\mathbf{M}}$ is a matrix with dominant eigenvalue equal to one with **q** as the corresponding (positive) eigenvector. The left hand side of equation [6.31] stands for the totality of inputs, and the right hand side for the totality of outputs. Equation [6.31] thus expresses the economy's self-reproducing property with sectoral capacities at level **q**.

Equation [6.31] will be our alternative starting point for investigating the consequences of a big disruption. The equation can be used to provide an answer to questions like: Is there a post-disaster output level such that the economy can self-reproduce? And if so: How do we find that level? In situations where the economy's production intensities do not have the right proportions (i.e. those prescribed by the dominant eigenvector of matrix $\breve{\mathbf{M}}$), we will need a new guiding equation, based on [6.31], to point the way to go. That will be an alternative view of the Basic equation, to be discussed below.

It is useful now to continue with indicators that express how much capacity is still available after the calamity (e.g., in our example, a flood) when compared with the pre-disaster situation. To this end, we introduce (n+1) parameters γ_i ($0 \leq \gamma_i \leq 1$) which indicate the fraction of the production capacity of industry i that is lost after the flooding.[69] Let **C** be the vector of the remaining sectoral capacities. We then have:

$$\mathbf{C} = (\mathbf{I} - \breve{\mathbf{\Gamma}})\,\mathbf{q} \qquad [6.32]$$

where

$$\breve{\mathbf{\Gamma}} = \begin{bmatrix} \gamma_1 & & 0 \\ & \ddots & \\ 0 & & \gamma_{n+1} \end{bmatrix} \qquad [6.33]$$

---

[69] Here labour is commodity n+1.

Clearly, if we assume that [6.31] represents a pre-flood situation, $\breve{\mathbf{\Gamma}}$ is the (n+1) dimensional zero matrix. If $\breve{\mathbf{\Gamma}}$ is not the zero matrix, we have, correspondingly, $\breve{\mathbf{M}}\,(\mathbf{I} - \breve{\mathbf{\Gamma}})\mathbf{q} \neq \breve{\mathbf{\Gamma}}\mathbf{q}$, unless $\breve{\mathbf{\Gamma}}\mathbf{q} = \gamma\mathbf{q}$ with $0 < \gamma \leq 1$. In the latter case, the economy is shrinking proportionally and replicates at $100\,(1 - \gamma)$ percent of its earlier level. If the diagonal elements of matrix $\breve{\mathbf{\Gamma}}$ are not equal to such γ, $(\mathbf{I} - \breve{\mathbf{\Gamma}})\mathbf{q}$ is not an eigenvector of matrix $\breve{\mathbf{M}}$, and the economy cannot replicate in the same proportions.

To continue, let us consider how the input side of [6.31] has changed after the flood. With capacities changed, the available inputs are given by:

$$\breve{\mathbf{M}}\,(\mathbf{I} - \breve{\mathbf{\Gamma}})\,\mathbf{q} = \breve{\mathbf{t}} \tag{6.34}$$

where $\breve{\mathbf{t}}$ is the (column) vector of the row sums of the left hand side (extended with the term t_{n+1} total for the labour equation compared to equation [6.18]). Let us consider equation [6.34] in more detail:

$$\begin{bmatrix} a_{11} & \cdots & a_{1n} & h_1 \\ \vdots & & \vdots & \vdots \\ a_{n1} & \cdots & a_{nn} & h_n \\ l_1 & \cdots & l_n & 0 \end{bmatrix} \left(\begin{bmatrix} 1-\gamma_1 & 0 & 0 & 0 \\ 0 & \ddots & 0 & 0 \\ 0 & 0 & 1-\gamma_n & 0 \\ 0 & 0 & 0 & 1-\gamma_{n+1} \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_n \\ L \end{bmatrix} \right) = \begin{bmatrix} t_1 \\ \vdots \\ t_n \\ t_{n+1} \end{bmatrix} \tag{6.35}$$

We observe again that although [6.35] may look like an input-output system in equilibrium, it clearly is not; it just provides a survey of possible inputs into a post-disaster ‘next round’.[70] Apparently, in a very concise form, this equation expresses the disturbed proportions between inputs and outputs in the post-flood situation.[71] In fact, in terms of form and purpose, equation [6.35] is similar to equation [6.18]. That is why we have decided to assign to both the name Basic equation, distinguishing between what we call the basic formulation (equation [6.18]), and an alternative design (equation [6.35]). Other possibilities to derive a similar sort of equations exist as well, based on the specified assumptions behind the transformations. The *Basic equation*, thereby, is an artificial construction only to be used as an initial stepping stone. Immediately below we shall observe the link that now has been made with Von Neumann growth theory.[72]

For situations where $0 < \gamma_1 = {}_{\ldots} = \gamma_{n+1} = \gamma < 1$, we have a proportionally shrunken economy as we may observe in equation [6.36].[73]

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[70] Just as in the case of interpreting equation [6.17], we see this corroborated by calculating the implied input coefficients: dividing the elements of the i^{th} column of the matrix on the left-hand side by t_i does not reproduce the correct pre-disaster intermediate input coefficients.

[71] We again observe that proportions within the columns of the ‘intermediate part’ and within the ‘final demand’ vector have not changed. This is due to the fact that each column i is multiplied by the same fraction (1-γ_i).

[72] Recall also equation [3.8] here, where we have the same interpretation.

[73] The same observation has been made by Cochrane, 1997a, p.2.

$$(1-\gamma)\begin{bmatrix} a_{11} & \cdots & a_{1n} & h_1 \\ \vdots & & \vdots & \vdots \\ a_{n1} & \cdots & a_{nn} & h_n \\ l_1 & \cdots & l_n & 0 \end{bmatrix}\begin{bmatrix} x_1 \\ \vdots \\ x_n \\ L \end{bmatrix} = (1-\gamma)\begin{bmatrix} x_1 \\ \vdots \\ x_n \\ L \end{bmatrix} \qquad [6.36]$$

This also corroborates with our findings during a numerical example exercise in Section 6.5.2, where we found a proportional ‘implosion’ of an economic system to the level of the most disturbed sector.

6.6.1. Comparison of the Basic and the Alternative Designs for a Basic Equation

Let us now look again at the basic equation [6.35] which is an alternative to the Basic equation [6.18]. We need to rearrange equation [6.35] to be able to compare the two formulations. First, we rewrite to:

$$\begin{bmatrix} a_{11} & \cdots & a_{1n} & h_1 \\ \vdots & & \vdots & \vdots \\ a_{n1} & \cdots & a_{nn} & h_n \\ l_1 & \cdots & l_n & 0 \end{bmatrix}\begin{bmatrix} (1-\gamma_1)x_1 \\ \vdots \\ (1-\gamma_n)x_n \\ (1-\gamma_{n+1})L \end{bmatrix} = \begin{bmatrix} t_1 \\ \vdots \\ t_n \\ t_{n+1} \end{bmatrix} \qquad [6.37]$$

Further rewriting gives:

$$\begin{bmatrix} (1-\gamma_1)a_{11}x_1 & \cdots & (1-\gamma_n)a_{1n}x_n & (1-\gamma_{n+1})h_1L \\ \vdots & & \vdots & \vdots \\ (1-\gamma_1)a_{n1}x_1 & \cdots & (1-\gamma_n)a_{nn}x_n & (1-\gamma_{n+1})h_nL \\ (1-\gamma_1)l_1x_1 & \cdots & (1-\gamma_n)l_nx_n & 0 \end{bmatrix}\begin{bmatrix} 1 \\ \vdots \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} t_1 \\ \vdots \\ t_n \\ t_{n+1} \end{bmatrix} \qquad [6.38]$$

Because by definition $a_{ij}x_j = z_{ij}$, and $h_iL = f_i$, equation [6.38] can be readily reduced to the form:

$$\begin{bmatrix} (1-\gamma_1)z_{11} & \cdots & (1-\gamma_n)z_{1n} & (1-\gamma_{n+1})f_1 \\ \vdots & & \vdots & \vdots \\ (1-\gamma_1)z_{n1} & \cdots & (1-\gamma_n)z_{nn} & (1-\gamma_{n+1})f_n \\ (1-\gamma_1)l_1x_1 & \cdots & (1-\gamma_n)l_nx_n & 0 \end{bmatrix}\begin{bmatrix} 1 \\ \vdots \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} t_1 \\ \vdots \\ t_n \\ t_{n+1} \end{bmatrix} \qquad [6.39]$$

The transformation of the new basic equation [6.35] into equation [6.39] resembles the basic equation [6.18], yet one may also notice a difference. We shall reproduce equation [6.18] for ease of comparison:

$$\begin{bmatrix} (1-\gamma_1)z_{11} & \cdots & (1-\gamma_n)z_{1n} \\ \vdots & \ddots & \vdots \\ \vdots & \ddots & \vdots \\ (1-\gamma_1)z_{n1} & \cdots & (1-\gamma_n)z_{nn} \end{bmatrix} \begin{bmatrix} 1 \\ \vdots \\ \vdots \\ 1 \end{bmatrix} + \begin{bmatrix} \sum_i (1-\gamma_i)\, f_{1i} \\ \vdots \\ \sum_i (1-\gamma_i)\, f_{ni} \end{bmatrix} = \begin{bmatrix} t_1 \\ \vdots \\ \vdots \\ t_n \end{bmatrix} \qquad [6.18]$$

Comparison of the two Basic equations [6.39] and [6.18] yields interesting conclusions. Essentially, both basic equations reflect the situation immediately after a calamity, yet each in a slightly different manner. In the basic formulation [6.18], each of the sectoral final demands f_j was premultiplied by the composite factor $\sum_i (1-\gamma_i)$, which reflects the assumption of proportional labour force loss relative to sectoral production capacity. The difference is, first of all, that in the new post-disaster equation [6.39], final demand is multiplied by the loss factor γ_{n+1}, which reflects the decrease in demand according to the number of people lost due to a disaster. At the same time, in the alternative post-disaster equation [6.39], labour inputs per sector (in the $(n+1)^{\text{th}}$ equation) are reduced according to the technology requirements, i.e. the respective γ_i factors.

The difference between the reduction of final demand and the labour input leads to the conclusion that the interpretation of basic equation [6.39] deviates slightly from [6.18]. Our alternative design for the derivation of the Basic equation, extending matrix $\breve{\mathbf{\Gamma}}$ with an additional γ_{n+1} parameter for the loss of human victims, the choice of expression for physical terms, and the formulation of the input-output system as a closed system including the labour equation, as described in this Section, has led to the formulation of equation [6.39]. While consumers are also workforce, in equation [6.39] a discrepancy in the post-disaster situation between the people who need to be fed (expressed in the need to satisfy consumption needs in the new vector of post-catastrophe final demand) and the people employed as labour force in production (expressed in the wages paid to workers, and thus the capability to produce goods and services in the disrupted economy) becomes explicitly apparent. Finally, we should remark that it remains a matter of choice which model formulation will be chosen.

In our goal to return to the pre-disaster proportions within an economic system, we may turn to the Von Neumann model that we have briefly introduced in Chapter 1. The reason is that final demand and labour supply are fixed, and determine the scope of production. In other words, when we endogenise both **f** and *L*, as we did in developing our alternative Basic equation in Section 6.6, this results in a closed input-output system; our goal of reproducing the pre-calamity proportions points in the direction of Von Neumann types of models.

6.7. THE VON NEUMANN-LEONTIEF APPROACH

Below we shall briefly discuss Von Neumann's model for expanding *and* contracting economies. We shall see that the model addresses a different problem than Leontief's model. Von Neumann rather focuses on the right proportions and prices in the light of a specific goal. The model nonetheless shares a number of basic properties with Leontief's such as the description of productive activities in terms of production functions expressed in terms of input and output coefficients. Differences with Leontief are that unlike Leontief's industries, Von Neumann's industries are characterized by joint production, i.e. each industry can produce more than one product. Furthermore, the matrices of input and output coefficients are rectangular, i.e. the number of commodities need not be equal to the number of activities. Finally, the model focuses on one particular type of growth. The balanced or proportional type of growth is characterized by the fact that the industries grow at the same rate, say 5 percent per year. This implies the possibility of industries that produce more output than it can sell to the other industries. This 'extra' output is a waste, and may pose questions of free disposal.

As mentioned, a most important difference is the difference in focus. Von Neumann's model focuses on the selection of commodities and activities in the light of an overall, macro-economic objective. This is quite unlike Leontief's model where these choices already have been made. So, Von Neumann describes a selection process in the light of a particular question. This question is a deceptively simple one: Which selection of goods and activities should be made so that all activities in the set minimally grow at the same rate, which are the corresponding inter-sectoral input and output proportions, and which prices do obtain? The model also tells us which commodities are overproduced, and which activities are inefficient in the sense that output values do not cover input values. The question may be simple; the proof of the basic theorem is extremely complicated and involved an entirely new type of fixed point theorem (in later version, the proof was much simplified, see e.g. Kemeny, Morgenstern and Thompson, 1956). The model also tells us which commodities are overproduced, and which activities are inefficient in the sense that output values do not cover input values.

Proportions under balanced growth (or contraction!) stay the same over time. Von Neumann also imposed a number of conditions to guarantee economic interpretability. Most interestingly, the model specification includes the first explicit reference in input-output history to duality between the real output and price version of the same model. (That is, the internal relations in the 'real' sphere imply corresponding internal relations in the associated price model and *vice versa*).

Let us now briefly introduce the model itself: **A** be the (*m*,*n*) matrix of input coefficients, and **B** the corresponding (*m*,*n*) matrix of output coefficients.[74] Let furthermore **x** indicate the total output vector, and α - the uniform rate of balanced growth. Finally, let the notations $\underline{>}$ and $\underline{<}$ stand for the concepts 'greater than' and 'less than', with at least one equality, respectively.

An equilibrium solution to the model is formed by vectors **x** *and* **y** *and numbers α and β that satisfy the following five axioms*:[75]

$$\mathbf{Bx} \geq \alpha \mathbf{Ax} \qquad [6.40]$$

That is, we are looking for an output vector **x** such that all industries grow with the rate α while at least one industry grows at exactly that rate.

$$\mathbf{pB} \leq \beta \mathbf{pA} \qquad [6.41]$$

---

[74] This output matrix **B** should not be confused with the capital matrix in Leontief dynamic model of Section 5.3.

[75] Here we follow the approach in Kemeny, Morgenstern and Thompson (1956).

This property is the competitiveness condition; no industry can make a profit.

$$\mathbf{p}\,(\mathbf{B}-\alpha\mathbf{A})\,\mathbf{x}=0 \qquad [6.42]$$

This is the free disposal assumption. If a commodity is oversupplied, its price is zero, and there are no additional problems of elimination.

$$\mathbf{p}\,(\mathbf{B}-\beta\,\mathbf{A})\,\mathbf{x}=0 \qquad [6.43]$$

That is, inefficient (i.e. loss making) processes are not used. Finally,

$$\mathbf{pB\,y}>0 \qquad [6.44]$$

This axiom requires that the total value of all produced goods is positive. Von Neumann imposed, as an alternative to the last axiom, the so-called indecomposability condition. It implies that the economy cannot be decomposed in independent sub-systems.

$$\mathbf{A}+\mathbf{B}>0 \qquad [6.45]$$

The axiom [6.45] implies that the economy cannot be decomposed in independent sub-systems.[76] Although in many cases satisfying these axioms will imply $\alpha = \beta$, equality of α and β in general case require additional axioms, see Kemeny, Morgenstern and Thompson (1956).

The Leontief closed model can be viewed as special case of Von Neumann's model. If $m = n$, and if $\mathbf{B} = \mathbf{I}$, the Von Neumann model coincides with Leontief's model.[77] We have:

$$\mathbf{x}=\alpha\mathbf{Ax} \qquad [6.46]$$

So, if processes are combined in these exact proportions, we have balanced growth or decline. If $\alpha > 1$, we have economic growth.

$$\mathbf{p}=\beta\,\mathbf{pA} \qquad [6.47]$$

Prices precisely cover the interest rate. Equilibrium implies:

$$\mathbf{p}\,(\mathbf{I}-\alpha\,\mathbf{A})\,\mathbf{x}=0 \qquad [6.48]$$

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[76] See further Steenge en Konijn (1992) on the role of this axiom in relation to the phenomenon of joint production

[77] We should add that Leontief explicitly opted for certain simplifications such as considering only one-commodity activities. Many of these simplifications have been introduced to avoid a host of problems in empirically implementing the model.

and

$$\mathbf{p}\,(\mathbf{I}-\beta\mathbf{A})\,\mathbf{x}=0 \qquad [6.49]$$

The total produced value is positive:

$$\mathbf{p}\mathbf{I}\,\mathbf{x}=\mathbf{p}\,\mathbf{x}>0 \qquad [6.50]$$

and finally:

$$\mathbf{A}+\mathbf{I}>0 \qquad [6.51]$$

i.e., **A** is indecomposable. In this case, we have straightforwardly $\alpha = \beta$. If $\alpha = \beta = 1$, we have the closed model of Section 6.6. Both models are *closed* in the sense that there is no special category of primary inputs or resources. The system propagates without additional inputs ‘from outside’.

6.8. ELEMENTS OF A COST-BENEFIT ANALYSIS

In this Section we shall outline what may become an underlying principle of performing a cost-benefit analysis (CBA) of preventive measures taken in the pre-disaster period within an input-output framework. This may help us compare the costs associated with the implementation of preventive measures with the loss figures of an expected disaster in the a-priori analysis setting. Avoidance or decrease of losses compared to the benchmark situation would then count as benefits associated with the measure at hand. Carrying out a CBA requires a well-defined threshold for the comparison of alternative scenarios to the benchmark, or what is sometimes referred to as the ‘doing nothing’ option (see, for example, MAFF, 2000, p.19, for the discussion of this issue).

Our model, by construction, allows us to investigate the consequences of large-scale adversities *at the level of the national economy*. Besides, one of the crucial features of our approach is that the model also is able to determine losses emerging at the micro level. This is due particularly to the development of modern GIS technologies, which make it possible to bring together and link the geographical and economic data, to be used in the input-output framework. The advantage of this construction is that it allows us to model changes within an economic system (either before, after or during a major shock), independent of the level at which they emerge, be it the sector, the region or the individual establishment.

The possibility for performing a CBA in our input-output framework finds its origin in the type of scenario analysis, to which we have briefly referred to in the previous Section. For a CBA this is an indispensable tool to use in the analyses of the options for policy and action in disaster preparedness, and to select the ones that are most desirable, effective or optimal for a decision-maker in a particular policy setting. In this Section, we shall consider three options as an illustration of which measures may be taken to limit the consequences of a possible major calamity. We shall provide what can be seen as an outline for the way in which a CBA can be constructed in the framework of our model.

We shall first consider one of the simplest options of protection against a flood. Suppose that the expected disaster extensiveness can be limited due to the installation of some additional flood barriers, like artificial dikes or levees, as indicatively reflected by the reduced shaded area in Figure 6.11 when compared to Figure 6.2. In that case, we might observe that this action would have saved two production facilities. As a result of this we may expect that the recovery process from this reduced flood might be speedier as fewer connections within an economy are disturbed, and achieving a new status-quo thus would be facilitated.

Another possibility that can be analytically considered is the installation of additional prevention mechanisms around *specific* production facilities that may be of critical or of strategic importance for the entire economic network (see Figure 6.12). For example, it may be an important area where so-called ‘critical’ sector activities are clustered (see Chapter 3, Section 3.2.4), the loss of which would imply over-proportional upwards or downwards effects throughout the system. Suppose now, that part of the plants that now could have been lost, if no action is taken, would have been saved by a targeted protection effort.

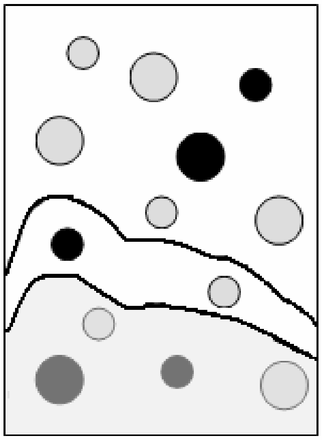

Figure 6.11. *A smaller-scale disaster after the imposition of an additional flood protection barrier*

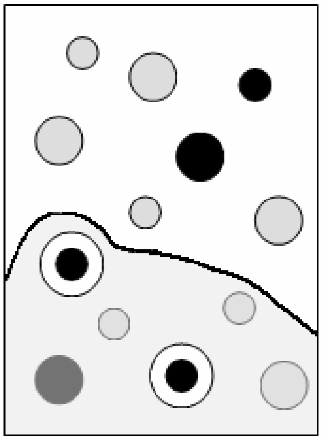

Figure 6.12. *Different effect of a disaster after the targeted protection of selected production facilities*

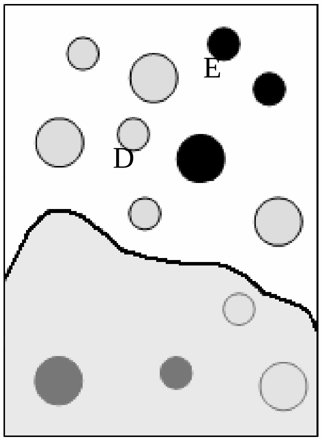

Figure 6.13. *Reduced vulnerability to a disaster after spatial redistribution of economic activities*

The two options for protection policy as described above are essentially directed at structural engineering solutions to keep water outside designated areas. An alternative to such policies would be a provision of incentives for economic agents, which are specifically directed at spatial rearrangements; see Figure 6.13, where two production facilities (D and E) are moved from the disaster area, and now are located in the safe area, while the extent of an expected flood remains the same as in the original situation on Figure 6.2. For example, a public campaign in the flood-prone areas making inhabitants and businesses aware of existing flood risks, may lead in the medium and long term to changes in decisions connected to the choices of locations that economic agents make. We may expect that as a result of such a campaign, choices concerning residence and business locations may shift in favour of more protected or geographically safer areas. Such changes, if they take place, would mean a spatial reallocation of assets between various regions within a country (as a side effect of this option, some agents may also consider locations abroad that would lead to an undesirable outflow of economic activity). Another type of incentives that may trigger shifts in location preferences may be the creation of favourable tax conditions in relatively safe areas (using e.g., principles of off-shore zones). Prohibition to build new property in the disaster-prone areas or a decision of the authorities not to guarantee protection from disasters and subsequent losses to the new-comers (for example, the latter is the case in the dune zones in the Netherlands, see e.g Commissie Poelmann, 2005), are among possible indirect measures aimed at restricting the growth and accumulation of economic and other valuable assets in the endangered zones.

With respect to the possible policies aiming at spatial rearrangements,[78] we have to note that it is important that each incentive is carefully reviewed in conjunction with an array of related factors in a broad context. These can be socio-demographic and psychological factors (where such aspects as ‘trust in government’ and the creation of credible expectations may play an important role), real estate markets and international competitiveness, *et cetera*. This additional information is indispensable in the process of the construction of credible scenarios.

Analysis of the imposition of possible protection measures, evidently, involves a trade-off. Considerations whether or not to undertake investments in additional protection have to be weighed against lower direct and indirect post-disaster costs for the entire economy, as well as the distribution of costs on the micro- and meso-levels. Mathematically, prevention measures undertaken in the pre-disaster situation, as determined in our model described in the previous Sections, would have a number of implications. Engineering solutions, as imposition of additional protective barriers for the first two cases (depicted on Figures 6.11 and 6.12), would first of all affect pre-disaster consumption (as represented by vector $\mathbf{f}$ and matrix $\mathbf{F}$ in equations [6.1]-[6.9]), as for example part of public spending would be invested in the construction of flood defences, which in a sense remain ‘idle’ until the event of a flood. At the same time, the second implication for our model would be a decrease in the γ_i’s, as in equations [6.11] to [6.18], as part of the production facilities would appear unharmed relative to the initial situation of ‘doing nothing’ (Figures 6.11 and 6.12, compared to Figure 6.2).

A different type of implications for our CBA analysis may be involved for the case of adaptive change in spatial activity distribution. Here, a broader range of pre-disaster effects throughout the economy is to be expected. It may affect almost every element of an input-output system already in the pre-disaster situation. On the one hand, for example, due to spatial movements of production activities and labour, the labour input vector $\mathbf{l}$ may change (in particular if multi-regional tables are available); also, due to regional differences, in commodities such as property or utilities, also (regional) consumption patterns as given in $\mathbf{f}$ may change. Such changes would influence in turn the construction of the $\mathbf{M}$ matrix in equations [6.4], and the construction of the $\underline{\mathbf{M}}$ matrix in equations [6.5] through [6.7]. Major restructuring within an economy may also trigger shifts in production functions, which would affect the $\mathbf{A}$ matrix. All of these possible or expected changes in the pre-disaster situation, as

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[78] In the context of concepts defined in Chapter 2, we would refer to these as an example of an adaptation strategy.

an economy adapts to a potential hazard, can be analysed as taking place separately or together in various combinations on the basis of scenario work. A calamity, which would now cause less damage to the 'renewed' economy, would result in lower values for the relevant loss ratios, the γ_i's in equations [6.11] through [6.18], and ultimately in a different picture for total disaster costs. A new basic equation (of the type [6.18] or [6.39]) underpinned by the accompanying changes before and after a disaster can then be derived and analysed, also with respect to prospective recovery patterns.

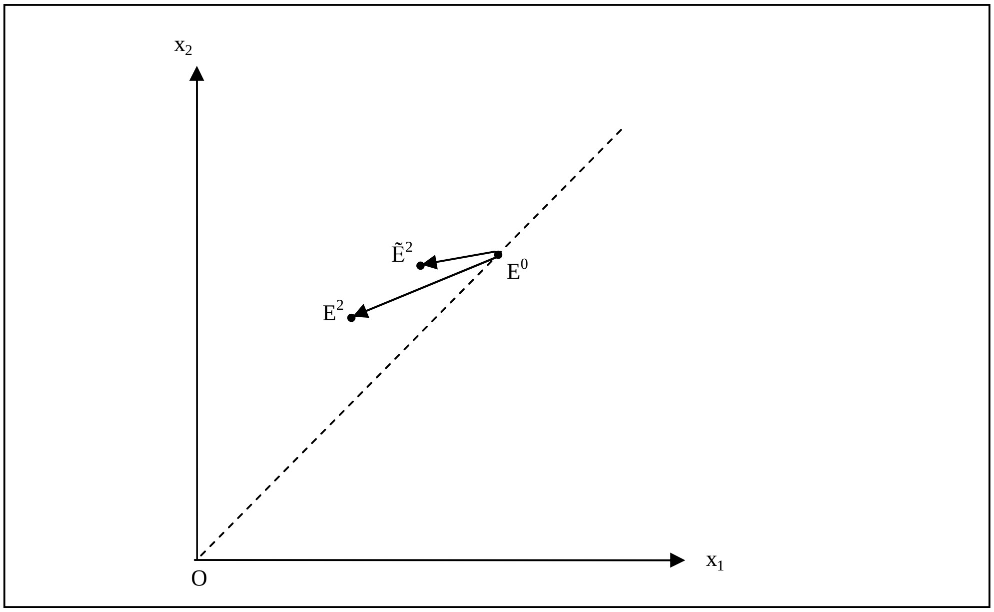

Figure 6.14. *Graphical illustration of the effects of adaptive strategies on disaster impacts.*

If we apply a two-commodity diagram, CBA can be illustrated as follows. In fact, the essence of such an exercise is to compare the effects (consequences in terms of economic loss in our case) of a shock in the initial situation to the effect of the same shock (which may effectively have a different extent) in the situation where pre-disaster adaptation and mitigation have taken place. This means that we may assume that as a result of mitigation measures taken, and adaptive processes taking place, the situation can be schematically depicted as in Figure 6.14. Due to improved resistance and resilience, the extent of the same shock as in our initial scenario is different in the adapted and additionally protected economy, the distortion can now be reflected as point $\tilde{\mathrm{E}}^2$ in the immediate disaster aftermath instead of E^1 in the baseline scenario. The benefits can be defined as the changes in losses in the improved situation (i.e., difference between E^0 and $\tilde{\mathrm{E}}^2$, and in bridging this gap) compared to the losses made in the initial situation (i.e., the difference between E^0 and E^1, and bridging that gap).[79] The costs made for the implementation and subsequent restructuring of the economy in the *ex-ante* situation have then to be weighed against the expected benefits. (We have to make a not here that cost-benefit analysis has developed its own particular set of

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[79] We follow the definition of loss that we have established in the framework of our model earlier in this Chapter, Section 6.5.

concepts and measures. Bridging the differences between concepts of CBA and multi-sectoral analysis will be a necessary next step.)

One of the ways to improve resistance and resilience is to apply the developed GIS techniques in risk and emergency management (see also Appendix 5A). GIS techniques, with the extensive background database, can be applied in disaster management for analysing historical events and their consequences for specific locations, strategic planning as well as assisting in tactical planning on the spot in the immediate disaster aftermath. Prompt mobilisation, analysis and visualisation of data within GIS can also help gaining insight into the potential repercussions of future calamities to support policy and action and forming an integrative approach, for example together with economic and hydrological or seismic modelling (see Chen, Blong and Jacobson, 2003). This can be done based on a palette of scenarios for possible events, where analysis of emergency response and mitigation priorities can be performed visualising potential outcomes and bottlenecks, thus pointing to the areas where disaster preparedness should be improved. Finally, in the immediate disaster aftermath, GIS will prove indispensable for providing information for planning and coordination of recovery efforts, thus addressing an array of rigidities, contributing to the speedy restoration of broken links or the establishment of new links. This means that a GIS, with its entire set of techniques and data, is an important aspect in the field of disaster studies to be addressed and integrated better in the future, as one of the means to significantly improve system preparedness and response.

6.9. SUMMARY AND DISCUSSION

In this Chapter we have proposed an input-output based methodology for discussing sudden shifts in the economic structure as a result of a major shock. Our study has explored the possibilities the methodology may offer. Input-output, despite its limitations, seems an excellent choice if, for whichever reason, the stricken economy is confronted with *rigidities*, be they of a technological or an institutional nature. In this contribution we have focused on one particular aspect of a catastrophe, namely its *size* in relation to the country or region that is affected. The consequences of the catastrophe have been interpreted in terms of a disruption of existing connections within an economic network. This is an aspect that input-output analysis, with its characteristic focus on connections and interrelations, seems to have been neglected largely.

In this Chapter we have focused on the model's properties in terms of rigidities. As we pointed out, the term may need additional attention. The Leontief model often is associated with rigidities. They have almost exclusively a technological interpretation. That is, only particular types of activities are possible or allowed for technological reasons. That is, substitutes are impossible, or very difficult to realise. However, there are additional rigidities, rather of a *social* or *institutional* nature that intensify the extent of technological rigidities in the immediate disaster aftermath. One of these is what may be called the full employment 'imperative'. That is, employment targets are seen as one of the most important properties of an economy, and policies should be directed at that. Employment will invariably be affected after a disaster. It is true, of course, that in the disaster's aftermath many new jobs are created such as in the emergency sphere in medicine, waste collection, and, general, restoration. However, these are mostly temporary and 'exceptional'. In terms of regular jobs associated with the traditional occupations, there often will be a substantial problem.

We have employed the concepts of vulnerability, resilience and adaptability (discussed in Chapter 2) as helpful means for structuring our thinking about the disaster, the recovery thereafter, and over-all preparedness. Analytically we have distinguished three stages. These are: first, the immediate disaster aftermath, where the system's vulnerability plays a major role; second, the recovery and reconstruction processes where resilience is most important; and third, pre-disaster precautionary strategies aiming at preparation for a potential shock. Here we meet the concepts of adaptability and mitigation.

Regarding the first stage, we have put forward what we view as the '*Basic equation*' [6.18]. This equation offers a detailed survey of the imbalances that exist immediately after a disaster. To be precise, we actually defined the notion of 'imbalances' in terms of this equation. The Basic equation also offers a structured insight in the choices the economy has to make (which is pointed out by a number of authors, *inter alia*, Gilbert, 2002). Naturally, a great many paths can be followed after the direction (such as restoring the pre-catastrophe situation) has been determined. But even such a central goal is only one of many the economy may wish to consider. Our approach makes use of the possibilities that GIS and other spatial information systems offer in obtaining a detailed insight in the geographical dimensions of the catastrophe.

During the second stage, recovery possibilities can be examined, where scenario analysis is considered to guide the way in the uncertain world of post-disaster analysis. For steering the recovery, it is important to possess a set of feasible scenarios and select desirable ones in advance. Insights into the vulnerability and revival capacity of an economic system are essential for policy advice, which forms the core of the third stage. Here, precautionary measures can be analysed, possibly weighted and evaluated in terms of their gains (often, expressed in terms of lower or avoided losses) against costs made to implement those measures.

We have also pointed out that 'costs' should be defined against the background of the adopted recovery scenario. A good insight in *where* the economy wants to be at the end of the recovery stage, and *how* it plans to achieve it, are essential here. Here again the term 'rigidity' comes to mind. We should –again– think of generally shared opinions such as the importance of employment and maintaining established consumption packages, all finding their meaning in terms of the circular flow concept.

Further, we present an alternative derivation of a Basic equation for the description of survived capacity in a post-disaster economy. In this case, we essentially focus on one type of imbalances, namely a disruption in the relation between the net product an economy can produce and the remuneration of the labour force. After a major disaster, there will be a mismatch between net product and the demands made by labour. To this end, we leave the traditional *open* model and have focused on a special *closed* model including a labour equation explicitly, in which the relevant imbalances can be traced more directly. In this alternative formulation, households' consumption is treated as an input. This approach provides an alternative to the formulation [6.18] discussed above, where we have used the labour equation as an interim tool to account for final demand loss.

In the alternative formulation of the Basic equation [6.39], we in fact ended up with a type of hybrid Leontief-Von Neumann model. This way, our recovery planning exercise receives a new interpretation. Essentially, because Von Neumann growth model stresses the importance of observing *proportionality* in an economic system, this also becomes our leading principle in recovery path selection. Namely, this setting makes us follow such a direction, which returns the disturbed economy to its pre-disaster proportions (both in terms of intermediate input requirements and final demand). In this manner, all the resources that are physically in place over the needed proportions are considered in excess, and hence as being ‘superfluous’. Moreover, if it is not possible to dispose of them on foreign markets, they will become idle, and in this setting will be seen as a loss. At the same time, those resources that are available only in limited amounts act as bottlenecks for putting the system back on track, at which recovery efforts should be directed in the first instance to ensure fast reconstruction.

Possible extensions of the model are in several areas. Applications in inter- and multi-regional analysis easily come to mind. There are many more possibilities than have been addressed in terms of the model. The use of GIS data and coupling an economic model with GIS techniques also offers ample opportunities for extending empirical work in the field of disaster analysis. Besides, featuring a synthesis of theory and practice, the model may be a good candidate for use in policy analysis and advice. For example, post-disaster policy will be needed to accompany market mechanisms in steering the circulation and distribution of the resources in appropriate ways between the various agent categories. In this context, we propose that vulnerable countries should develop a portfolio of post-disaster relief and reconstruction policies. It is here that more specialised models such as the dynamic models of Section 5.3 in Chapter 5 may find their place.

In this thesis, we have focused exclusively on imbalances in the absolute sphere. Further attention, in any case, should be devoted to questions concerning the circumstances under which price mechanisms can guide the economy in its path to a ’normal‘ equilibrium situation. Because standard input-output theory only provides sustaining prices in the equilibrium situation, we will need here an accompanying theory of prices to support the post-shock choices. Underlying any such theory must be insight in what markets can perform in the situation at hand, and what the role of government should be. Another issue is the role of the infrastructural systems like transportation, utility services and communications. We have not addressed this point explicitly in this Chapter. This is because we tacitly have assumed that disturbed links between firms in affected and non-affected areas can be replaced without undue cost by new or extended links between firms in the non-affected area. However, in establishing these connections, new types of transportation and transaction costs will arise, which must be accounted for in later modelling efforts. Similar observations are valid regarding the time aspects involved to properly distinguish between static and dynamic issues. Thus, in a number of steps, we have moved from the Basic equation introduced in an open Leontief model, to a Basic equation defined in a closed model. We started with some diagrams in ‘DOSSO-style’, and later on moved to a set of figures closer to the Von Neumann-Leontief set of closed models. This provided an introduction to the interpretation of a catastrophic event in highly developed countries in terms of *contracting* Von Neumann-Leontief logics.

A concluding remark is here at place. The suggested model, of Von Neumann-Leontief type, where ultimately the system is forced to shrink triggered by the level of the most hit sector, is clearly an extreme. In this formulation, where rigidities take the central place, and no substitution (in fact, no resilience) is possible, we arrive at a ‘radical’ conclusion that every input and every sector is critical. This means, that our proposed model provides a maximum estimate of economic loss. Here, the indirect effects, which are triggered by the direct ones are at their highest. This implies that every improvement in the level of the system’s resilience will yield a *lower* total damage figure. For modelling and analysis of such options, a different set of assumptions, and, possibly, a different procedure will be necessary (after the construction of the Basic equation) to arrive at a new state of equilibrium. The aim of our ‘modelling exercise’ was to provide a clear and consistent framework for the analysis of a major disturbance in a modern, highly interconnected economy. Further improvements and extensions of the current framework together with fine-tuned scenarios, are left for the future research agenda. Also, the linearity assumption underlying the model belongs to the set of issues that needs further inquiry. For example, the proposed Basic equation will not always result in a linear implosion of the system; an assumption of ‘perfect flexibility’ would turn the Basic equation into an actual equilibrium, thus implying a structural break (caused by a heterogeneous shock).

Part Three

Analysis

Chapter 7

Model Illustration: a Hypothetical Flooding in Randstad (the Netherlands)

7.1. INTRODUCTION

Currently, several sources exist which contribute to the increase in probability of flooding in the Netherlands. The ones attributed to climate change are: increased precipitation; melting of snow caps in the Alps, triggering the occurrence of extremes in peak flows; and the sea level rise. Others are the gradually subsiding ground level in the West of the country and an observed change in the bottom pattern of the North Sea, which might affect the wave patterns that reach the shores of the Netherlands. Altered wave patterns might in turn produce unexpected pressure on the dunes that protect the coast from inundation by seawater. This implies, that more pressure is put on the entire water management system in the Netherlands to adapt to changing circumstances, where modelling and analysis of economic vulnerabilities deem indispensable.

We shall take the case of a hypothetical (yet possible) major flooding in the Netherlands as a reference case in our research. In the preceding Chapters we have provided a basis for analytical approach towards modelling economic consequences of large-scale disturbances in modern economies. In the current Chapter, we shall apply this model to an illustrative case study of a simulated flooding in the central part of the Netherlands to set the agenda for a debate around changing attitudes in the Dutch water and flood management in the next Chapter with our model as a possible tool for decision-making support.

The main objective of this illustrative case study is to analyse the consequences of a relatively severe inundation in the Netherlands, and to show how the developed input-output methodology for disaster analysis can be used to perform such an exercise. To do this, we shall fist describe the data connected to this case study and link it to the needs of our modelling approach. Next, we shall perform the calculations for losses incurred in the economic network as a result of interruptions of the circular flow. We shall select a return to initial proportions as a basis scenario for our recovery stage. Further, we shall compare the obtained results with the earlier study of ours where ad-hoc methodology for loss estimation was used. We shall close with summary and discussion.

7.2. DESCRIPTION OF THE CASE AND THE DATA [80]

In this Section, we shall present the hypothetical case study that we shall use as an example to illustrate the economic model that we have developed (Chapter 6) for studying effects of disruptions in the circular flow as a result of a massive calamity in a modern economy. Challenges presented by data availability as well as data compatibility will be discussed here. But before that, we shall devote a few words on the specificity of situation in the Netherlands in the domain of flood protection.

7.2.1. Dike Rings in the Netherlands

The Netherlands takes a special place in the spectrum of countries provided its efforts in the field of flood protection. Because of its location, in the course of time the country has developed a particular sort of landscape. The part of the country vulnerable to flooding from sea or rivers is subdivided into a number of so-called dike-ring areas. Each dike-ring area is surrounded by a ring of natural or manmade water defences, such as dikes, dunes, concrete structures or high grounds. There are 99 of such dike-ring areas in the country, including the ones along the Meuse. Figure 7.1 below resembles only those dike rings that were originally included in the Flood Defence Act (1996); later, in 2005 also dike rings along the river Meuse with standards for dike overtopping once in 500 years were added to the Act.

A dike-ring area consists of one or more polders or low-lying areas. In the Western coastal area, the standard for the exceedance probability is most stringent (once per 10.000 years), followed by the Southern and Northern coastal areas (once per 4.000 years). Several of the smaller dike-ring areas (in terms of population and economic significance) are faced with exceedance probabilities in the neighbourhood of once per 150 or 200 years (in Limburg). The reason for having differences in standards for different areas was the observed variation in population and capital densities in the different parts of the Netherlands. All these standards are laid down in the Flood Defence Act (1996). Estimated maximum loss per dike ring varies greatly, ranging from 160 million euro in the island of Terschelling to 300 billion euro in Central Holland, dike ring 14 (MTP, 2005c, p.8).[81]

In the coming Sections, we shall provide a study of economic loss based on the specifications of a particular (hypothetical) flood in central Holland (dike ring number 14). It is one of the largest dike-ring areas, comprising the densely populated Western part of the Netherlands and covers important parts of the provinces of Noord-Holland, Zuid-Holland, and Utrecht, and includes several major cities (Amsterdam, Rotterdam, The Hague, Leiden, Haarlem, Gouda).

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[80] We are highly indebted to Christiaan Logtmeijer for data collection and computational assistance during the early stages of this research, as well as to the Delft Cluster "Risk due to Flooding" programme team for provision of the data and close cooperation.

[81] The estimated loss figures above are provided as an indication for relative economic importance of various dike rings as given in MTP report (2005c). Possible argumentation on methodological issues around the estimations and models of economic damage is given in Chapters 3 and 4 of this thesis.

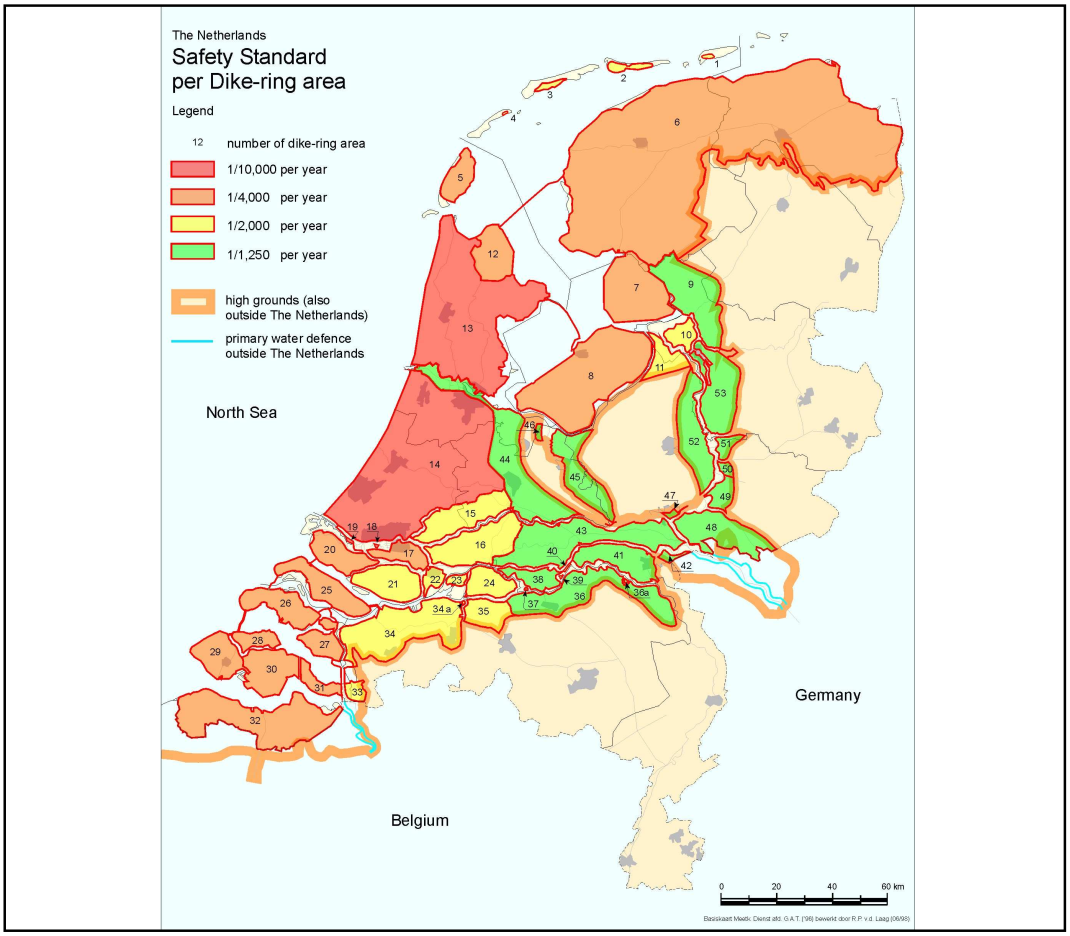

Figure 7.1. *Safety Standards per Dike Ring in the Netherlands*
(source: MTP, 2005d, p.13)

7.2.2. The Case

For our application exercise, we shall use the example of a dam break in the province of South Holland in the Netherlands, dike ring 14, which should serve a fruitful playground for modelling the consequences of vast economic disruption. This case study was initiated within the Delft Cluster theme “Consequences of Flooding”, project “Risk due to Flooding”, where a hypothetical dike breach near Rotterdam was simulated, with a massive flooding of major parts of the Randstad area as its consequence. Randstad is the biggest urbanized area surrounding the so-called Green Hart in the Netherlands and a conurbation in Europe, lying in four provinces and including three major Dutch cities.

The location of a river dike breach near Rotterdam (along Hollandse IJssel or the Nieuw Maas) was selected as the one expectedly leading to a most disastrous flood (Asselman and Heynert, 2003, p.11). The reason is that supply of water at this location in the river Rhine is large; as are the differences between the water levels during the periods of high and low discharge. Also, the elevation of land behind the dike in this area reaches at places more than 6 meters below the sea level. Finally, because of the absence of floodplains near Rotterdam, water can flow through the gaps in the dikes even when water levels at the river drop to a very low level.

The flooding of the southeastern Randstad area, following the simulation developed by Delft Hydraulics (*ibid*), would occur very rapidly, i.e. within 5 hours. It would take 5 days more before the entire area of about 50.000 ha becomes inundated. The output of the hydrological model thus comprises a map with water depths for the case of flood caused by a dike breach near Rotterdam (see Figure 7.2 below, where the arrow shows the point of the breach). Orange colour provides the borders of the dike ring; blue colours indicate the depth of the flood water (the darker the colour, the higher the depth of the flood, reaching 5 to 6m in its extreme).

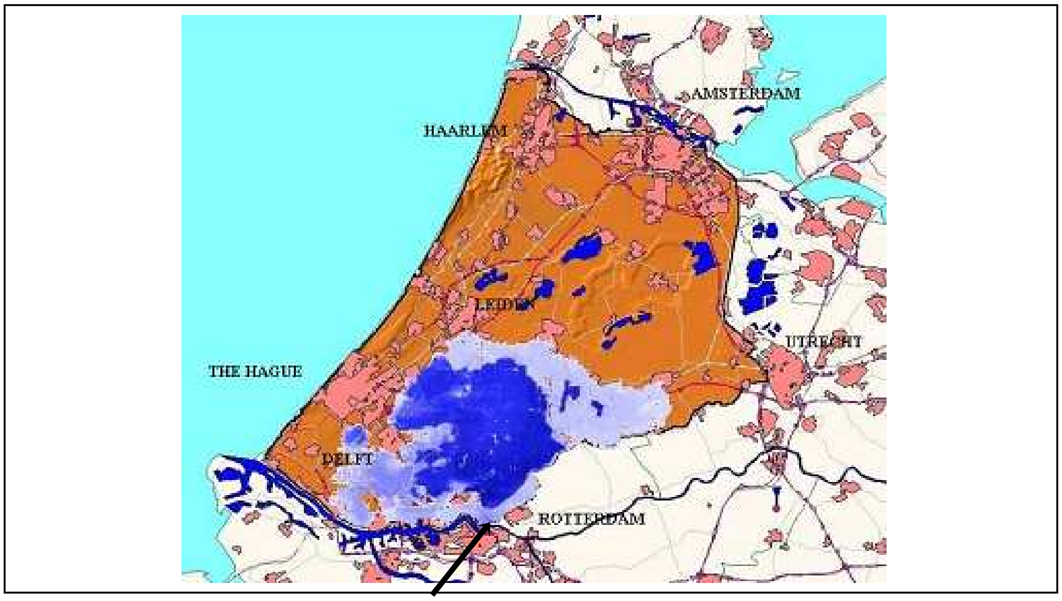

Figure 7.2. *Maximum water depths computed for the hypothetical case study of a dike breach near Rotterdam*
(source: Asselman and Heynert, 2003, p.15)

Some facts below from the Delft Cluster research team will illustrate the extent of this hypothetical simulated flooding. Because of the large volume of water stored in the flooded area ($1,37 \times 10^9$ m^3), it would expectedly take 160 days to pump all water out (*ibid*, p.15), causing substantial environmental contamination of the area (Stuyt *et al.*, 2003) and over 70.000 expected victims (Asselman and Jonkman, 2003). Van der Veen *et al.* (2003b) provided the estimation of expected economic losses within the Delft Cluster project, which were calculated based on a rudimentary input-output type of model. The indication of economic damages was mounting up to 5 to 10% loss of value added in productive sectors depending on the recovery scenario (we shall discuss these figures in Section 7.3.2). In the current Chapter we shall provide the estimations of economic losses associated with the interruptions in circular flow with the help of our newly developed input-output model. Because we shall use flooding data based on the same initial conditions as in the Delft Cluster study of 2003, it will also enable us to compare the two economic loss estimations.

Every time a researcher has to apply a theoretical model to a case study, two major challenges are faced. The first is that data availability is not always guaranteed; it is important that systematically collected, reliable data is available on the spot. At the same time, another challenge concerns data compatibility. Even if reliable data is there, it not always fits the requirements of the theoretically developed model. Often, additional calculations, data from other sources and / or proxies are needed to bridge the gap and keep the model operational for practical purposes. Also in the case of Delft Cluster study, some limitations were encountered, which we shall discuss in the next Section.

7.2.3. The Data

Economic data

The basic economic data requirement of our theoretical model to carry out the analysis of economic repercussions of large-scale disruptions is the availability of an input-output transactions table as a basis to model the disturbed relations in an economy. In fact, bi-regional tables for every province of the Netherlands for the year 1997 compiled at the University of Groningen became available for us in the framework of Delft Cluster inquiry. The bi-regional structure of the input-output tables provides us the information about the transactions within a province of the Netherlands, and between the respective province and the rest of the economy, for all 12 provinces. The transactions table was constructed according to a semi-survey method (Eding and Stelder, 1995), in which survey methods were combined with technical methods to construct the transactions table in the time-period between 1992 and 1997 (see also Appendix 5A to Chapter 5). Some may claim that the data in the tables may be out of date; however literature (Eding and Stelder, 1995) suggests that the main characteristics of the economic structure in the ‘business as usual’ time remain the same. This makes it possible for us to assume that most relationships within the Dutch economy remain stable these days as well.

Our case study takes place in the province of South Holland; this means that we shall use the respective input-output transactions table for the province of South Holland and the rest of the country. However, our model for analysing major disruptions in an economy as it stands now is developed in a single region input-output context. This means that we would have to ‘reduce’ the bi-regional transaction table to a single region. This can easily be performed by row-wise and column-wise summations of transactions in two locations by respective industries. For example, we would sum the purchases of the agricultural sector in South Holland[82] and in the rest of the country to obtain a single column of expenditure for the agricultural sector on the country level. The same procedure for the sales of each industry would be followed to obtain a row of sectoral revenues on the country level. Note also that these input-output data are in guilders, so to adjust for euro prices, one needs to divide each entry by 2,2 (see Appendix 7B).

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[82] In fact, we could have taken any bi-regional input-output table for the Netherlands when we had decided to reduce it to a single region table. Theoretically, it should have given us in the end the same input-output table.

While after some manipulation our input-output table for the country became useable, it still did not possess any reference to the location, which we need to reflect the spatial dimension of the flood. In the process of development of our model, we realised that without a geographic link, understanding and modelling of economic impacts of major calamities and their repercussions throughout an economy cannot be complete. Thus, the challenge that we face also in the empirical study is to combine the output of the hydrological model provided by Delft Hydraulics (as described above) with the input-output table in such a way that it fits the needs of the economic model that we have presented in Chapter 6. The literature on earthquake hazard modelling (French, 1998) suggests the use of a conceptual framework, which links physical damage to economic functions using the spatial relation both have in common. Translating this to the case of a large-scale flood, this means that we can make a conceptual model depicted in Figure 7.3. Today, we have geographic information systems at hand that represent this spatial relationship (GIS, discussed in Appendix 5A to Chapter 5).

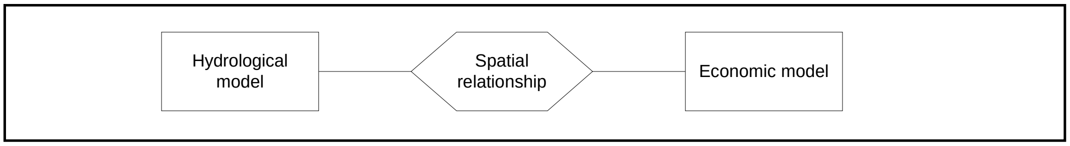

Figure 7.3. *Conceptual model for GIS-analysis (French, 1998)*

French (*ibid*, p.51) further claims: “The spatial analysis techniques available in a GIS provide a mechanism for linking the formerly separate physical and economic modelling efforts.” To bring in this connecting innovative element that was not available before, we need to look for a data set, which would resemble an explicit link between the spatial characteristics of both the hydrological and the economic model. For these purposes, we could utilise a set of economic data that is used in the HIS-SSM[83] damage model. We shall recall that it is based on the so-called standard method, see our discussion of economic damage modelling in Chapter 4 and (Vrisou van Eck and Kok, 2001). This is a dataset, which is generated by Dun and Bradstreet Marketeer and Prospector (D&B). It contains information on the location, size (number of employees) and the sort of economic activity (per 4 digit SIC code) of any place in the Netherlands for the year 2002. We have to notice here, that to be able to use the micro-level D&B data, it needs to be reclassified according to the SBI coding, which is used in the Dutch input-output transactions tables. This is done by using a reclassification schemes to transform SIC data into SBI data; the schemes are available from Statistics Netherlands (see www.cbs.nl). See Appendix 7A for the description of both schemes.

The spatial element in the D&B dataset is thus a six-digit zip code. Besides, we have a dataset of all zip codes in the Netherlands with their geographical X and Y coordinates. This makes it possible for us to geo-reference economic data, i.e., to link specific economic data to a geographical position, and thus connect the information on the location of economic activity and the map of the hypothesised flooding. Ultimately,

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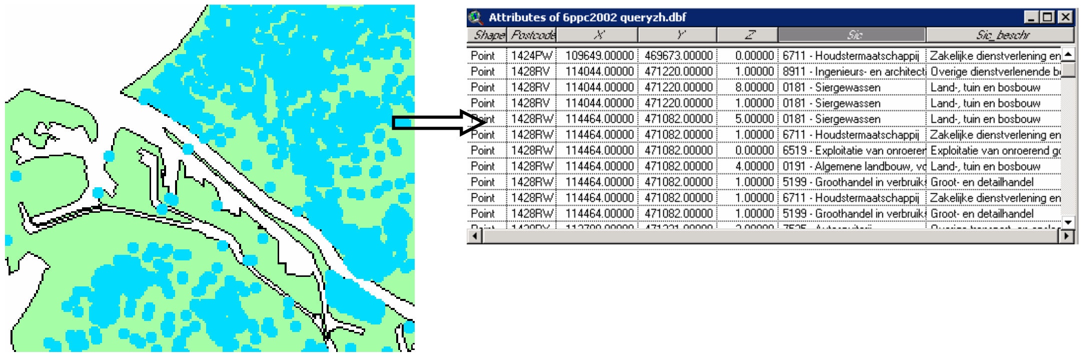
[83] HIS-SSM is the policy support Module for Victim and Damage estimation within the Dutch High Water Information System (in Dutch: Hoogwater Informatiesysteeem – Schade- en Slachtoffer module). Other policy-support modules are the Flooding Module and Evacuation Module. The operational part of HIS consists of Monitoring and Registration. For more information, see www.hisinfo.nl.

this results in a database in which we have, per zip code, data on economic activities categorised by the type of activity and size of activity in terms of number of employees.

GIS and Data Transformations

To manipulate and fit all the data into one fully consistent base, one needs special GIS software, Arcview[84]. We could download both the output of the hydrological model with the map of the simulated flooded area (see Figure 7.4) and the D&B data on economic activity into a GIS environment. It is a system in which we can visualize (with the help of a map) any kind of data that has a geo-reference, in its geographical context. Furthermore we can select and analyse the data within this setting for specific analytical purposes.

Figure 7.4 shows the operational implementation of the conceptual model of Figure 7.3. It shows how a link can be made between data on a micro-level and data on a more aggregated level. Each row entry in the table to the right contains a disaggregated micro-level economic data with a 6-digit zip code. The zip code file can be called a cornerstone of our analysis, and contains the centres (with X and Y coordinates) of every zip code in the Netherlands. The description of the zip code is given in column two of the table, and the X and Y coordinates are given in respectively column 3 and 4. Column 5 represents the number of employees and in columns 6 and 7 the description of economic activity can be found. The blue dots on the map to the left represent the centres of zip codes, which is also the source of the geo-reference.



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Shape	Postcode	X	Y	Z	Sic	Sic_beschr
Point	1424PW	109649.00000	469673.00000	0.00000	6711 - Houdstermaatschappij	Zakelijke dienstverlening en
Point	1428RV	114044.00000	471220.00000	1.00000	8911 - Ingenieurs- en architect	Overige dienstverlenende b
Point	1428RV	114044.00000	471220.00000	8.00000	0181 - Siergewassen	Land-, tuin en bosbouw
Point	1428RV	114044.00000	471220.00000	1.00000	0181 - Siergewassen	Land-, tuin en bosbouw
Point	1428RW	114464.00000	471082.00000	5.00000	0181 - Siergewassen	Land-, tuin en bosbouw
Point	1428RW	114464.00000	471082.00000	1.00000	6711 - Houdstermaatschappij	Zakelijke dienstverlening en
Point	1428RW	114464.00000	471082.00000	0.00000	6519 - Exploitatie van onroere	Exploitatie van onroerend g
Point	1428RW	114464.00000	471082.00000	4.00000	0191 - Algemene landbouw, v	Land-, tuin en bosbouw
Point	1428RW	114464.00000	471082.00000	1.00000	5199 - Groothandel in verbruik	Groot- en detailhandel
Point	1428RW	114464.00000	471082.00000	1.00000	6711 - Houdstermaatschappij	Zakelijke dienstverlening en
Point	1428RW	114464.00000	471082.00000	1.00000	5199 - Groothandel in verbruik	Groot- en detailhandel

Figure 7.4. *Example of the link between spatial and economic data*

Schematically, in the chart below (Figure 7.5) the overview of our data and manipulations therewith are depicted as a visualisation of Figure 4 above. On top of the flowchart we find the four datasets, which are used in this study. Below these, in rectangles the operations we apply to the data are represented: one is a join between two datasets, and another is an overlay between two spatial entities.

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[84] For more information on Arcview, as well as other GIS and mapping software, consult designers' website at http://www.esri.com/software/arcview/index.html.

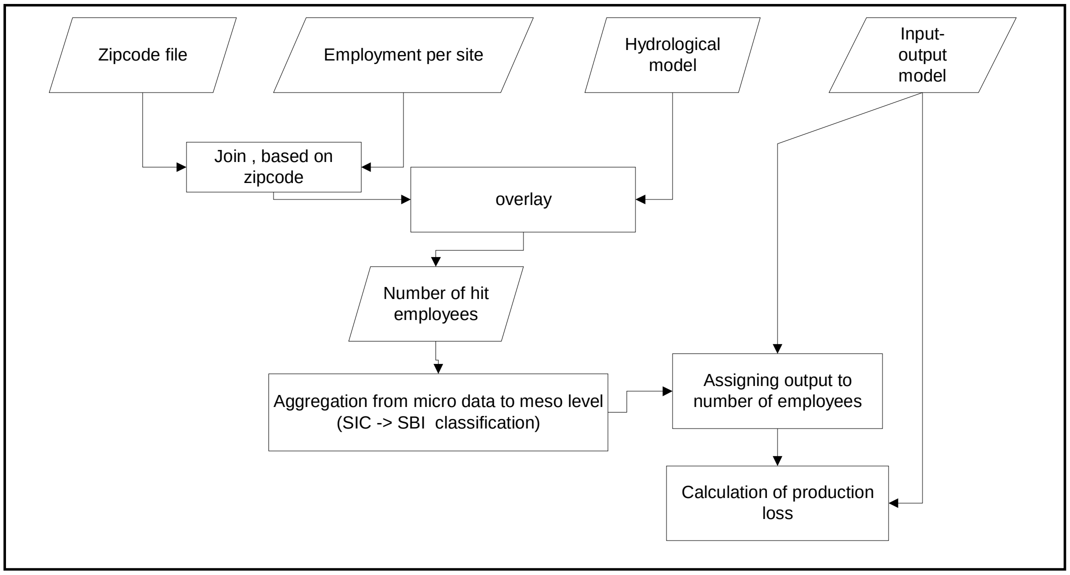

Figure 7.5. *Flowchart of data and data manipulations.*

With the GIS software, we can make an overlay of multiple layers of geo-referenced information to select the zip codes, which are affected by the flood. This overlay operation is in fact the combination of the output of the hydrological model (in the form of the map, see Figure 7.2) and the economic D&B data. Since we have different types of geo-referenced information, putting the hydrological model (the shape of the end-result of the flood-simulation) 'on top' of the economic micro-data will select the companies and factories that will be directly affected by the simulated flood. This in turn will provide us information on the precise nature and size of economic disruption, namely with the number of employees per economic activity per zip code that are affected by the flood.

Here we might face two problems, however. One of them has to do with temporal discrepancies between the two data sets we dispose of. We have mentioned above that the input-output tables we have at hand are dated to the year 1997, while the D&B dataset on economic activity with a zip code attribute dates to 2002. With regard to that, Eding and Stelder (1995) conclude that input-output data can still be valuable for analysis, as soon as economic structure remains constant in the industrialised countries for years during 'business-as-usual' periods.

Another problem that surfaces is the fact that we have only employment data per economic activity per zip code (from the D&B data set), while we are aiming at analysing disruptions in the circular flow that affect productive output and value-added. In fact, here we are talking about estimating the extent of disruption per sector of activity, which we can only make via employment loss, and then connect it to our input-output model where we use disruption coefficients to analyse economy-wide effects. Yet, this does not seem to hinder the quality of our analysis, as the literature points to other examples, where production capacity loss was approximated by employment losses (see French, 1998). Because more detailed data (e.g., on production volumes, value added or wages) is not currently available, we should consider employment as an acceptable proxy for the estimation of production loss for our illustrative case study. To apply this approach, we have to assume that output per sector (that is known to us from the input-output table) is proportional to the number of employees (which is available from the D&B data set), which is also confirmed in the literature (see Rose and Benavides, 1998). This implies that we can calculate sectoral loss coefficients, γ_i's (see also Chapter 6, Section 6.4), in the following manner:

$$\gamma_i = \frac{N_{i(affected)}}{N_{i(total)}} \qquad [7.1]$$

where $N_{i(affected)}$ is the number of employees affected by the flood in sector *i*, which we obtain from the geo-referenced overlay of the hydrological and economic data; and $N_{i(total)}$ is the total number of employees for sector *i* before the flood obtained from the D&B data set. The sectoral γ_i's are found in Appendix 7A.

This transformation will complete the link between the two economic data sets and finalise the transition from hydrological map with defined borders of the simulated flooding to the zip code file with geographical coordinates, which is linked to the D&B data set on economic activity and employment, and ultimately to the input-output table that we use in our economic consequence modelling. In the following Sections, we shall describe the calculations that we shall perform for the above mentioned case study with the help of the newly developed input-output disaster model, and compare its results with our earlier attempts to estimate economic loss (see Van der Veen *et al.*, 2003b).

7.3. APPLICATION OF THE DESIGNED INPUT-OUTPUT DISASTER ANALYSIS MODEL

In the previous Section we have described our case study in the framework of the Delft Cluster project "Risks due to Flooding", and the data that were available for us to perform application studies within the project. We have outlined that a number of problems were encountered, such as accessibility to data, applicability of data and compatibility of data coming from different sources. We had to apply specified assumptions (see the previous Sections) to assemble the data in such a way that it became useable for our modelling purposes. In the end, we succeeded to obtain approximated coefficients for the loss of production capacity per economic activity sector (γ_i's) based on the hydrological map of flooding in central Holland. In this Section, we shall continue with the calculations for the hypothetically simulated dike breach case near Rotterdam and its possible consequences for the Dutch economy.

Our developed model for analysing the effects of major disturbances in modern economies is essentially input-output based (as described in Chapter 6). We recall, that the input-output model in its standard formulation has undergone some adjustments to be able to account for disproportions and disequilibrium that are observed in the direct disaster aftermath. Further development is given to the recovery options that essentially require clearly stated strategies. Finally, a type of CBA analysis is possible to be performed with the proposed model to study the effectiveness of pre-selected preventive measures and disaster preparedness. The model is essentially split in three stages (disequilibrium, recovery and a CBA of a-priori adaptation), where latter two stages are suggested to be carried out with the help of scenario analysis instead of prediction (a brief background for scenario analysis is given in Chapter 5, Section 5.3.

In this case study, we shall effectively look at the first two stages (applying the basic design, see Chapter 6, Section 6.3), which will keep our analysis comparable to our earlier results of economic loss estimation based on the preliminary approach (Van der Veen *et al.*, 2003a). Further elaborations in the direction of studying and constructing credible scenarios for a cost-benefit analysis in the preparedness stages are advised to be left for later inquiries. This means that for now we shall mostly concentrate on the reconstruction of the disequilibrium stage and sorting out the course for recovery planning.

The input that we need in order to be able to perform damage assessment with the help of our proposed input-output model is first of all, an input-output table, and, second, industry disruption coefficients. We have both of them at our disposal, and we believe each component needs some additional attention. In Chapter 5 we have described a basic input-output model, starting from the description of an input-output table. It is apparent that on the expenditure side, an input-output table should contain outlays of productive sectors for intermediate inputs (representing their technologies) as a part of the inter-industry transaction matrix, and expenditures on the primary inputs. Alternatively, on the income side, an input-output table should represent sales of productive sectors as rows of the inter-industry matrix, and final demand categories. In general, the construction and presence of an inter-industry matrix is rather straightforward; mostly, differences appear in which primary sectors and final demand categories are present. The input-output tables for the Netherlands dated 1997 contain four categories on the part of primary inputs that can be described as imports, taxes, wages and profits. The important category for our inquiry is ‘wages’ which we shall use in the input-output model transformation into the disequilibrium stage of disaster aftermath. Essentially, because here our primary inputs consist of four elements (as opposed to the 2x2 example in Chapter 6 where we have assumed the presence of a single primary input, i.e. labour) it suggests that, following the logic of our proposed model, only that part of final demand can be lost that is not consumed from the lost wages. This, in fact, provides some justification to the fact that disruption coefficients, γ_i’s, which we can use in our case, are based on the loss of employees rather than output (see Section 7.2.2). Also, because the link between the geo-referenced employment data set of D&B (as we also described above) and the input-output table is made through coefficients of lost labour force, the discrepancy in time between the two data sets should not be a problem. Essentially, finding the sectoral coefficients of lost productive capacity via the sectoral proportions of lost employment may be seen as one of possible proxies; another would be conventional loss of output; while other researchers might find value added loss as a justifiable option.

7.3.1. The Basic Equation: Transformations of the Input-Output Table

The first stage of our model results in what we call the ‘Basic equation’. Let us describe the calculations and transformations that the input-output table had to undergo to arrive at this equation. For reference, the initial input-output table is given in Appendix 7B.

In the course of our exercise, we shall follow the same order as outlined in Chapter 6, Sections 6.3 to 6.5 describing the basic design of our input-output model. Essentially we start with the calculations of the $\underline{\mathbf{M}}$ matrix, which consists of two matrices, **F** and **Z**. While the latter can directly be obtained as an inter-industry transactions matrix from the input-output table, the former requires more attention. We recall the definition of the **F** matrix, which is in fact a final demand vector dispersed through all sectors as consumption bundles that workers buy proportional to their income. By construction, the **F** matrix has the same proportions across its columns reflecting identical preferences of all labourers; only between the columns proportions are different according to the wages earned, or in other words, the number of workers employed in the sector (see also equation [6.3]). Each column, thus, shows in which way wages are spent on various consumption goods. This means that we need to know the proportions in which final goods are consumed, and the values of wages paid (and consequently, earned) per sector to arrive at the **F** matrix. Wages paid to the employees are obtained from the input-output table (see Appendix 7B) as a part of primary production factors, alongside with imports, taxes and profits. Final demand proportions can be easily calculated by dividing each sectoral demand by the total value of consumption demand. The multiplication of the vertical final demand proportions vector (nx1) by the horizontal vector of wages (1xn) yields the matrix which we have defined as the worker's real wage matrix **F** (to be found in Appendix 7C). (Note, however, that the row totals of the **F** matrix do not coincide with the final demand vector from our input-output table, because the former represent only that portion of final demand that is consumed from labour income.)

Adding together matrices **Z** and **F** brings us the matrix $\underline{\mathbf{M}}$, to which a special role is attributed in our modelling. We should again refer, respectively, to the equations [6.8], [6.9] and [6.10]. Matrix $\underline{\mathbf{M}}$, which reflects inter-industry transactions in both intermediate and final goods, enables us to connect physical losses brought by a calamity to both sides of economic construct, i.e., production and consumption. Provided the knowledge of location and the extent of disturbance, we can split the pre-disaster $\underline{\mathbf{M}}$ matrix into two parts, representing the lost and spared parts of the economy. This provides the advantage of being able to directly trace the damage 'as it occurs'. We do this with the help of sectoral loss coefficients, the γ_i's (see equation [7.1], Section 7.2.3).[85]

The next step is to split the $\underline{\mathbf{M}}$ matrix into two matrices reflecting the immediate post-disaster situation (see equation [6.16]). In fact, we are mostly interested in the recapitulation of the spared part, which will go on with recovery. To have the accounts of what is left, the $\underline{\mathbf{M}}_S$ matrix (see equations [6.16] and [6.17] in Chapter 6), we in fact need to multiply the columns of the $\underline{\mathbf{M}}$ matrix by the respective sectoral factors of surviving capacity (1-γ_i), as given in Appendix 7A. Finally, we have to separate the final demand part and assemble it again as a vector to give the table the corresponding input-output format. Via column-wise addition, we obtain the vector **t** and arrive at what the Basic equation (i.e., equation [6.18]). What we have now obtained should rather be called the 'basic disequilibrium input-output table'. This has been reproduced in Appendix 7D. We should mention that in this situation, final demand has shrunken proportionally,[86] all disproportions thus stem from the new total output. Total production loss at this stage is recorded at 2.68%.

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[85] Above we have also discussed how we were able to obtain these coefficients for our case study. Namely, we utilised the knowledge about the loss of employed personnel by location and productive sector as a result of the simulated vast flooding in the West of the Netherlands.

[86] This can also be observed by looking at equation [6.17], where each row element $f_{\bullet j}$ is multiplied by the same fraction of survived capacity (1-γ_i).

We recall that a Basic equation (in fact, a table as in Appendix 7D) is ‘merely’ an accounting table that reflects what is left in the economic network directly after a distress. This is not yet a balanced system, at least not in the sense of its pre-disaster proportions. We may only observe here factual remaining capacity of the system in ‘translated’ from the initial physical damages as a result of a hazard. On the one hand, because the Basic equation shows the potential of the system, it does not necessarily mean that the system is able to produce this amount of total output provided new intermediate and final demands. On the other hand, even if a system is able to produce this new output, it will be able to utilise all of the resources to its advantage available in disproportion only if it possesses a high level of resilience. Unfortunately, practice has shown that systems under attack are not able to react fast and efficiently and thus are not flexible enough to adjust instantaneously to new circumstances. In fact, provided the chaos and uncertainty in the immediate calamity aftermath, some of the resources may appear to be superfluous as the system attempts to achieve its pre-disaster proportions. We have chosen to focus on this trajectory as one of the possibilities for recovery, discussed in Chapter 6. For our current exercise this means that final output proportions should be restored according to the pre-disaster ones, i.e., the $\mathbf{t}$ vector should become a ‘sensible’ vector $\mathbf{x}^{new}$. We have adopted for this vector an output vector having the *proportions* of the pre-disaster total output vector. However, the elements of our ‘$\mathbf{x}^{new}$ vector’ reflect the 5,10% loss as discussed earlier (the last but one column of Appendix 7D). The last column in Appendix 7D presents the differences (in fact, the ‘superfluous’ production). We thus may observe that if we transform vector $\mathbf{t}$ into the vector $\mathbf{x}^{new}$ following pre-disaster proportions, it would lead to a much higher, almost double, figure for the immediate production loss, namely 5,10%. This is due to the fact that, under the assumption of proportionality, the most hit sector plays a role of a bottleneck to all other (less damaged) sectors.

Furthermore, if we assume that in fact many rigidities are present, either of technological or of institutional character (discussed in Chapter 3), we may wish to calculate the effects of what can be seen as a ‘worst case’ scenario regarding immediate loss. If we think in terms of the loss factors, the γ_i’s, then the biggest disruption can be incurred if all sectors are damaged to the extent of the sector with the highest loss factor γ_i. In this ‘worst case’ scenario, the immediate output loss would be 6.03%. If we again assume that output should return to its pre-calamity proportions, total production loss would mount to 10,3%, which is in fact a proportional shrink of the whole system by the extent of the most hit sector.[87]

The ‘forced’ implosion of the system to the 10,3% level is observed due to the rigid assumption of extreme interdependency between all the sectors, for which every input is critical. This also shows the maximum amount of damage to be sustained by an economic system if this strict proportionality (without a possibility for substitution) is observed. In fact, the difference between the direct sectoral damages, γ_i’s, and the γ_{max} determine the extent of highest indirect damage.

It is important to mention here that in this exercise we have not applied a further multiplier analysis in its conventional input-output sense. Essentially, because we are dealing with the extreme situation of a very large shock, we involve the Basic Equation for the evaluation of initial damage in the framework of Von Neumann-Leontief type of model as we just described in the previous paragraph. In this case, multiplier analysis becomes unnecessary at the stage where we account for major disequilibrium and

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[87] We have described this case in the Section 6.6 (equation [6.36]).

sudden disproportionality in the entire economic system, with establishment of a new balanced network as a next step. At later stages, when the economy is back in balance (in term of its internal proportions), interindustry multipliers will make sense again and impact effects of a growing economy can be traced. Yet, at this moment we leave the design and analysis of possible reconstruction and development scenarios to further research, because this typically requires separate attention by itself. In particular, effort should then be directed at testing the sensitivity of the model to a change of assumptions.

7.3.2. Comparison and Interpretation of Results

In this Chapter, we decided not only to show the applicability of our developed input-output model to a practical exercise, but also to compare the obtained results with the ones from our initial Delft Cluster study (see below). There is no need to introduce the data for our earlier study, as now we are using just the same case of dike breach in central Holland. Yet, to be able to carry out a comparison between the two models, it is necessary to describe briefly our initial model setting.

The model was developed for the purpose of studying economic effects of a large-scale flooding in the Netherlands based on the case study we have presented in Section 7.2. It essentially consisted of two steps, which are the imposition of the initial shock and recovery thereafter (see Van der Veen *et al.*, 2003a; Bočkarjova, Steenge and Van der Veen, 2007). We then formulated what we called three scenarios, where in the first one we have performed standard input-output exercises; in the second and third ones we have attempted to manipulate the inter-industry matrix, respectively accounting for a more flexible and more restricted economic infrastructure. While during the standard exercise we were imposing the shock and recovery impulses via final demand and computing multiplier effects, it was rather carried out as a baseline scenario than a study of effects. This is due to the very fact that input-output in the way we used it in this case, is meant for impact analysis, not a major shock analysis. The second scenario presented a model, where losses in domestic goods were instantaneously substituted by imported goods so that production in the survived areas could go on. The third scenario (on the contrary), a ‘bottleneck’ scenario, reflected a decrease in both intermediate and final demands. Maximum loss fractions, γ_i’s, were used there to account for intermediate production losses, while the impulse on the final demand was introduced to account for consumption decrease.

For the comparison between our two models, only two formulations of the earlier version would suit, namely, the standard exercise and the restricted scenario. We shall compare the imposition of the initial shock in the earlier version of the model to the modelling of disequilibrium and return to balance in our current exercise (following the procedure described in the previous Section).

Following our newly proposed approach, the initial loss observed *directly* in the disaster aftermath (i.e., the result of the Basic equation) for the case of dike breach near Rotterdam would result in a 2,68% loss of production on the country level. Yet, if we consider that a system first needs to come to a balance from which recovery can proceed (which we achieve by imposing the pre-disaster proportions to the total output), then we obtain a 5,1% loss of output. The difference reflects that additional losses appear either due to technological feasibility to adjust, or due to the fact that, provided required proportions, some goods become superfluous. At the same time, if we compare these figures to the results of the standard input-output impact analysis from our earlier study, we could see 5,6% loss of production in terms of total output (we retrieve this number from our earlier study, see Van der Veen *et al.*, 2003b, Appendix 2). The reason for a higher outcome in this case may lie in the fact that in the latter instance, multiplier analysis was performed, where inter-industry multipliers were taken into account. As we mentioned above, currently we question the meaningfulness of multiplier analysis in disaster analysis at the initial stage where immediate disruptions and imbalances resemble themselves. We suggest that multiplier analysis is applied in later stages where the system has achieved its structure and is on the way of recovery. This means, that essentially the loss of 5,1% of production capacity obtained from our newly developed disaster input-output model marks the very beginning of the process where the economic system is trying to find the way it would follow in its reconstruction and recovery efforts. Possibly, more losses can be associated with it, so the ‘new’ estimate of 5,1% production loss and the ‘old’ estimate of 5,6% can be seen as converging.

For the case of bottleneck calculations, where a maximum disruption factor was applied in both Delft Cluster and current exercises, we have higher loss numbers compared to the calculations just presented in the paragraph above. Our new model suggests that the minimal production losses in the bottleneck scenario are 6,07%, and may amount up to 10,3% in case we assume the return to the pre-disaster proportions. At the same time, our earlier exercise witnesses 7,8% output loss. In fact, we may recognise that the loss figures just provided according to both models are of comparable dimension. In the Delft Cluster study, a bottleneck scenario was considered as an absolute maximum for our calculations. Our new results show an even higher number of output losses, which is in fact a proportional decrease of the entire system by the factor of highest sectoral loss (the one of the sector 39 ‘Other goods and services’). We suggest that this number is taken as an ultimate minimum, which, yet, does not reflect any resilient response that should certainly deflate this initial loss figure.

Once again, in this illustrative exercise, we have abstained from the analysis of recovery paths and adjustment strategies. Research into the resilience of economies to natural disasters (see *inter alia* Cole, 2004; Dalziell and McManus, 2004; Rose and Liao, 2005) has shown that a system’s ability to respond to the distress in a flexible manner results in much lower final loss figures, which take into account also reconstruction and recovery periods. With this preliminary study, we have shown that our developed input-output based disaster analysis model can be used for the purposes of practice-based exercises, and provides a guiding illustration for their implementation. It should also be mentioned that the level of precision and internal consistency of model applications to case studies depends on the availability of data and compatibility between data when numerous sources and data sets are used.

7.4. SUMMARY AND DISCUSSION

In this Chapter, we have taken a case study from our earlier work as a basis for an illustrative exercise to show if and how our developed input-output model will be operable. The case study, actually, stemmed from a hydrological model of a hypothetical dike breach near Rotterdam, resulting in a vast inundation in central Holland. Using additional economic data on employment per zip code, and connecting it to the map of the flooding in the contemporary GIS setting, we were able to retrieve employment loss coefficients per sector to be used as proxies for production capacity loss fed in our input-output disaster analysis model. During the exercise, we have learnt that the available data required additional corrections before it could be used, and making connections between various data sets required additional assumptions.

We may see that case study work opens up a different side of modelling, which now includes real life events, experiences and data. Because of the issues of data availability, accessibility and compatibility, researchers are forced to find ways of dealing with these problems, and thus often look for operationalisations of theoretical concepts, which can then be traced back to empirical data. When an empirical (re)interpretation of scientific constructs is not found, proxies become a way out to find an approximation of a concept among the existing statistical data. Yet, the search for empirically available data should not result in undermining the conceptual framework behind the theoretical model.

In our reality-driven exercise, we were aiming at showing that our proposed input-output disaster analysis model (introduced in Chapter 6 of this thesis) can be used for empirical purposes. In this hypothetical case study, we have provided a numerical exercise of losses caused by the interruptions of circular flow within a single economic system, as well as offered one of the options for return to the required internal balances, which conforms to the idea of ‘right’ proportions in the system. As an initial step of looking at modelling recovery and post-disaster development, we have assumed that returning to the pre-disaster pattern of production can be seen as a background scenario for other alternatives. We found that the immediate loss of output in the disequilibrium situation, which we obtain by means of our basic equation, constitutes a mere 2,7%, while correcting for proportions in total output would bring our estimation up to 5,1%, which does not differ much form the standard input-output exercise of introducing an impulse, that would yield 5,6% loss. A bottleneck scenario also results in the figures that are of the comparable magnitude as in our previous study. The current estimates are found to vary between 6,07% and 10,3% loss of output on the country level, while our earlier study has resulted in 7,8% loss for the initial disruption.

Because we have performed the calculations only for the immediate post-disaster stage, excluding for the time being recovery options and pre-disaster preparedness (both of which are touched upon in Chapter 6), we also question the use and meaning of a multiplier analysis exercise at this stage. The reason is that we see large-scale shocks as conceptually different from what conventional models often are analysing, i.e. minor or incremental changes that are somewhat ‘commonplace’. We claim, with the help of this study, that major shocks require a different way of thinking and thus also a special treatment in modelling terms. Our suggested model offers in this sense one of the ways in which major disturbances in modern economies can be analysed.

In the next Chapter we shall describe some of the trends in current Dutch water and flood management, and would like to point out the place that our suggested modelling framework may take in the light of recent developments.

Appendix 7A

Sector classification and disruption factors

No	Sector (SBI classification)	$N_{i(total)}$	$N_{i(affected)}$	$100\gamma_i$
1	Agriculture and forestry	87908	7803	8,88
2	Fishery	3588	4	0,11
3	Mining industry	2005	0	0,00
4	Food (agricultural)	27874	1444	5,18
5	Food (other)	58154	2170	3,73
6	Beverages and tobacco industry	27221	1798	6,61
7	Textiles	13188	195	1,48
8	Clothes	18181	292	1,61
9	Leather, shoes and other leather products	4821	101	2,10
10	Wood- and furniture industry (excl. metals)	44386	1250	2,82
11	Paper industry	17697	261	1,47
12	Graphic industry, publishing	100915	5641	5,59
13	Oil industry	142483	91	0,06
14	Chemical industry	97208	2790	2,87
15	Construction materials	40275	1972	4,90
16&17	Metal industry and production of machinery	221227	5941	2,69
18	Electrotechnical industry	65329	736	1,13
19	Transport	53475	429	0,80
20	Instruments and optical industries	42264	2166	5,12
21	Utilities	63199	3183	5,04
22	Construction industry	517209	33310	6,44
23	Retail and wholesale trade	1060458	76103	7,18
24	HoReCa	180699	16658	9,22
25	Reparation of durable goods	23830	939	3,94
26	Sea and air transport	31161	1309	4,20
27	Other transport	682884	13111	1,92
28	Communication-industry	67259	850	1,26
29	Banks	673587	20053	2,98
30	Insurance	88372	7471	8,45
31	Exploitation of real estate	235964	8942	3,79
32	Business services	101423970	515217	0,51
33	National government and social security	18115	506	2,79
34	Regional government and semi-governmental institutions	680	3	0,44
35	Education	147782	7669	5,19
36	Health care and veterinary	203338	13344	6,56
37	Culture, sport and recreation	62803	2597	4,14
38	Other services	438243	33968	7,75
39	Other goods and services	790734	81510	10,31

Appendix 7B

Input-output table for the Netherlands (1997)

Sectors	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	4600	0	6	18439	2092	33	22	4	2	19	9
2	0	0	0	0	10	0	0	0	0	0	0
3	33	1	260	66	101	13	9	0	0	15	128
4	37	0	0	2762	1376	4	0	0	57	0	0
5	7404	2	2	379	4062	245	16	0	0	0	64
6	0	0	0	0	44	165	0	0	0	0	0
7	2	6	0	1	0	1	355	77	0	21	7
8	0	0	2	2	7	1	12	120	0	1	1
9	0	0	0	0	0	0	1	3	74	19	0
10	52	4	0	10	21	16	0	0	0	307	48
11	24	0	8	262	579	273	36	2	7	32	735
12	4	0	12	159	336	228	19	9	4	35	49
13	173	68	21	8	48	11	11	3	2	23	12
14	258	5	34	131	448	165	295	8	62	214	188
15	78	0	0	28	95	157	0	0	0	10	7
16&17	853	0	237	199	263	176	77	34	17	66	86
18	6	0	47	11	26	11	3	2	0	16	19
19	9	31	13	0	0	0	0	0	2	0	2
20	12	0	1	10	13	8	4	4	5	3	9
21	1652	0	81	205	551	91	86	11	13	76	141
22	405	7	70	49	115	35	27	2	3	96	66
23	422	3	55	47	144	57	40	16	9	80	109
24	14	1	6	27	61	29	19	11	5	22	23
25	135	1	18	44	88	16	13	1	4	15	8
26	0	0	17	2	6	3	1	1	1	4	8
27	1	56	306	21	32	16	0	2	0	9	1
28	201	7	58	45	100	27	25	10	10	34	36
29	216	0	2	25	28	5	11	4	2	7	5
30	196	16	6	10	17	6	4	2	3	13	14
31	1	0	2	48	154	26	33	43	6	92	21
32	1006	29	277	775	1401	772	278	92	45	341	418
33	9	3	8	11	16	10	5	2	1	5	3
34	16	3	7	21	36	15	23	5	3	5	8
35	28	0	7	20	32	25	8	0	0	8	19
36	386	0	1	0	0	0	0	0	0	0	0
37	2	0	2	12	23	15	0	0	0	1	1
38	47	4	105	102	198	119	122	29	12	48	56
39	5	2	18	34	62	39	12	5	0	13	19
Imports	2319	87	2335	2175	15079	2638	2138	919	349	2523	2897
Taxes	2181	31	153	1633	3154	426	183	75	72	608	445
Wages	3461	203	944	2695	5432	1472	1424	494	305	2065	1823
Profits	15900	440	11800	1155	4017	2666	473	236	26	849	1301
Total	**42148**	**1010**	**16919**	**31623**	**40267**	**10015**	**5785**	**2226**	**1101**	**7695**	**8786**

Input-Output table (continued)

Sectors	**12**	**13**	**14**	**15**	**16&17**	**18**	**19**	**20**	**21**	**22**	**23**
1	6	6	62	12	29	9	12	6	85	53	62
2	0	0	0	0	0	0	0	0	0	0	0
3	1	334	1160	255	71	4	0	2	6821	195	34
4	0	0	50	0	0	0	0	0	0	0	19
5	0	0	256	0	1	1	1	2	0	26	32
6	0	0	33	0	0	0	0	1	0	0	91
7	1	1	19	0	7	5	10	4	0	13	178
8	6	3	29	2	31	3	11	7	0	0	204
9	0	0	0	0	3	2	1	0	0	0	9
10	5	0	101	129	53	14	54	53	0	1492	198
11	225	8	431	55	82	76	14	38	20	31	533
12	3914	32	288	25	210	92	68	44	18	77	2161
13	18	1005	1415	54	137	98	40	15	71	222	88
14	157	49	6623	195	617	373	472	180	83	1158	347
15	2	3	105	461	64	38	42	12	0	4731	153
16&17	102	106	583	145	7469	631	1191	208	265	4461	557
18	11	18	99	21	416	1197	1002	62	190	666	251
19	4	4	14	2	163	6	1729	12	2	68	77
20	16	14	53	8	88	82	90	126	53	92	293
21	122	83	986	271	945	249	129	85	1780	176	1283
22	110	55	321	85	352	101	55	26	48	18584	545
23	61	90	347	95	401	117	74	41	62	399	3698
24	54	31	191	25	203	119	67	28	13	36	765
25	37	7	52	31	61	44	33	19	47	630	1050
26	23	5	36	7	30	23	17	6	2	15	345
27	135	48	105	9	95	53	43	9	3	243	492
28	331	40	206	34	224	137	60	38	158	180	1804
29	21	2	43	11	51	16	15	4	25	169	1004
30	19	3	33	11	62	10	20	7	2	86	492
31	120	82	189	119	265	62	98	53	0	520	3372
32	1298	698	2580	539	2201	1217	813	264	202	2663	5561
33	17	7	32	3	22	19	15	4	1	34	106
34	129	34	82	10	63	37	33	32	529	56	217
35	67	74	206	22	105	147	37	9	32	28	136
36	0	0	0	0	1	0	0	17	3	0	0
37	150	7	29	1	17	14	6	0	3	4	158
38	164	149	573	99	383	289	133	48	152	295	729
39	44	17	111	23	85	43	20	9	34	143	705
Imports	3801	13144	16513	1977	13902	6551	6707	1072	3092	9854	9137
Taxes	448	335	2960	715	3441	1657	1762	271	1086	4950	2067
Wages	5791	923	9796	2210	14215	7349	4172	1570	3368	21760	38221
Profits	2716	1838	6017	1246	4950	3204	1233	669	5854	5533	27428
Total	**20126**	**19255**	**52729**	**8907**	**51515**	**24089**	**20279**	**5053**	**24104**	**79643**	**104602**

Input-Output table (continued)

Sectors	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**
1	136	11	52	79	7	13	6	75	6	5	128
2	46	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	12	49
4	898	0	64	0	0	0	0	0	0	16	8
5	1255	0	57	0	1	0	0	0	0	113	62
6	854	0	9	0	0	0	0	0	0	65	34
7	15	0	1	0	0	0	1	0	26	10	12
8	12	6	8	23	0	0	0	0	6	1	3
9	0	1	0	0	0	0	0	0	0	0	0
10	0	0	0	41	0	4	3	106	28	12	19
11	12	11	13	31	26	20	8	6	78	42	28
12	215	150	53	183	126	340	142	9	2930	409	226
13	25	19	331	352	28	14	15	8	73	141	102
14	34	57	13	39	7	12	5	46	194	132	67
15	0	10	0	2	0	0	0	109	0	28	53
16&17	9	142	56	368	97	80	61	83	193	335	196
18	19	42	84	60	88	79	30	181	75	523	109
19	0	241	125	192	3	9	5	0	9	755	11
20	12	41	31	48	13	29	20	43	101	32	95
21	555	177	39	439	47	161	88	73	265	234	361
22	183	65	152	844	1053	390	211	3114	207	1367	1876
23	51	89	115	319	55	166	113	467	440	253	128
24	378	106	39	139	46	151	128	6	928	315	119
25	61	193	14	954	20	176	144	0	671	70	56
26	0	0	801	42	47	20	9	0	22	36	6
27	12	33	575	1734	78	112	72	1	122	369	136
28	129	86	152	436	155	1598	218	74	776	516	264
29	44	19	24	43	0	186	811	0	117	295	438
30	189	105	19	150	1	68	3846	194	228	64	23
31	623	388	8	350	131	399	92	154	1156	364	390
32	1058	530	282	1674	365	1354	496	837	6609	1876	593
33	21	10	1	14	7	4	125	9	47	662	78
34	72	9	12	136	61	67	31	284	129	52	235
35	36	11	0	25	6	11	12	23	78	190	97
36	0	0	7	20	2	0	68	0	0	190	85
37	2	0	14	26	0	115	48	0	485	328	208
38	178	144	79	577	315	239	186	101	406	1269	742
39	86	26	10	34	23	24	4	27	182	0	0
Imports	1240	3396	6304	1833	471	380	1615	137	1485	2626	650
Taxes	1120	1124	124	1884	631	804	448	2806	1280	2621	1709
Wages	4582	3445	3114	14676	6205	9397	5111	2126	24495	19511	12673
Profits	5762	3051	2732	8271	5384	9958	1404	51593	15580	930	1294
Total	**19924**	**13738**	**15514**	**36038**	**15499**	**26380**	**15576**	**62692**	**59427**	**36768**	**23363**

Input-Output table (continued)

Sectors	35	36	37	38	39		Final demand		Total
1	1	69	48	65	38		16231		**42538**
2	0	10	2	9	0		933		**1010**
3	0	0	0	3	0		7352		**16919**
4	4	230	62	213	111		25718		**31629**
5	4	263	168	223	244		24749		**39632**
6	3	20	217	37	138		8304		**10015**
7	8	22	10	8	4		5031		**5856**
8	0	11	2	22	0		1690		**2226**
9	0	0	0	0	1		987		**1101**
10	7	0	6	53	97		4762		**7695**
11	27	51	15	43	1		4958		**8840**
12	407	171	93	257	3		6671		**20169**
13	60	27	60	103	0		14892		**19792**
14	51	437	33	387	30		39277		**52883**
15	8	8	10	15	0		2678		**8907**
16&17	57	38	8	97	10		31959		**51515**
18	53	48	70	54	19		18852		**24460**
19	0	8	0	29	0		16686		**20212**
20	29	129	21	53	19		3378		**5078**
21	345	427	298	721	0		10831		**24076**
22	450	239	189	315	0		47831		**79643**
23	61	97	54	97	3		99364		**108239**
24	38	139	198	160	0		15284		**19924**
25	52	49	57	111	0		8757		**13739**
26	2	5	7	7	0		13958		**15514**
27	55	59	53	143	0		30805		**36038**
28	155	349	591	314	0		5920		**15499**
29	4	0	51	34	0		22344		**26076**
30	27	51	38	90	0		9452		**15576**
31	97	369	154	848	0		51864		**62692**
32	526	757	1071	1568	0		16361		**59427**
33	0	42	50	39	2		35324		**36768**
34	1354	83	246	119	0		19110		**23364**
35	107	115	38	251	0		26869		**28879**
36	132	728	10	74	0		37132		**38856**
37	56	41	1192	70	54		9889		**12973**
38	565	1188	378	1008	0		24452		**35682**
39	1	32	10	53	0		2		**1957**
Imports	319	1822	326	1273	489		132635		**276210**
Taxes	854	1587	717	1511	694		118158		**166724**
Wages	20604	18857	3997	20748	0		1009		**300243**
Profits	2356	11087	2423	4457	0		6518		**232351**
Total	**28879**	**39665**	**12973**	**35682**	**1957**		**978975**		**2000927**

Appendix 7C

The matrix **F**

Sectors	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	78	5	21	61	122	33	32	11	7	47	41	130	21	221
2	4	0	1	3	7	2	2	1	0	3	2	7	1	13
3	35	2	10	27	55	15	15	5	3	21	19	59	9	100
4	124	7	34	96	194	53	51	18	11	74	65	207	33	350
5	119	7	32	93	187	51	49	17	10	71	63	199	32	336
6	40	2	11	31	63	17	16	6	4	24	21	67	11	113
7	24	1	7	19	38	10	10	3	2	14	13	40	6	68
8	8	0	2	6	13	3	3	1	1	5	4	14	2	23
9	5	0	1	4	7	2	2	1	0	3	2	8	1	13
10	23	1	6	18	36	10	9	3	2	14	12	38	6	65
11	24	1	6	19	37	10	10	3	2	14	13	40	6	67
12	32	2	9	25	50	14	13	5	3	19	17	54	9	91
13	72	4	20	56	112	30	29	10	6	43	38	120	19	202
14	189	11	51	147	296	80	78	27	17	113	99	316	50	534
15	13	1	4	10	20	5	5	2	1	8	7	22	3	36
16&17	153	9	42	120	241	65	63	22	14	92	81	257	41	434
18	91	5	25	70	142	39	37	13	8	54	48	151	24	256
19	80	5	22	62	126	34	33	11	7	48	42	134	21	227
20	16	1	4	13	25	7	7	2	1	10	9	27	4	46
21	52	3	14	41	82	22	21	7	5	31	27	87	14	147
22	230	13	63	179	361	98	95	33	20	137	121	384	61	650
23	477	28	130	372	749	203	196	68	42	285	251	798	127	1351
24	73	4	20	57	115	31	30	10	6	44	39	123	20	208
25	42	2	11	33	66	18	17	6	4	25	22	70	11	119
26	67	4	18	52	105	29	28	10	6	40	35	112	18	190
27	148	9	40	115	232	63	61	21	13	88	78	248	39	419
28	28	2	8	22	45	12	12	4	3	17	15	48	8	80
29	107	6	29	84	168	46	44	15	9	64	57	180	29	304
30	45	3	12	35	71	19	19	6	4	27	24	76	12	128
31	249	15	68	194	391	106	102	36	22	149	131	417	66	705
32	79	5	21	61	123	33	32	11	7	47	41	131	21	222
33	170	10	46	132	266	72	70	24	15	101	89	284	45	480
34	92	5	25	71	144	39	38	13	8	55	48	154	24	260
35	129	8	35	100	203	55	53	18	11	77	68	216	34	365
36	178	10	49	139	280	76	73	25	16	106	94	298	48	505
37	47	3	13	37	75	20	20	7	4	28	25	79	13	134
38	117	7	32	91	184	50	48	17	10	70	62	196	31	332
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The matrix **F** (continued)

Sectors	**15**	**16&17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
1	50	320	166	94	35	76	490	861	103	78	70	331	140
2	3	18	10	5	2	4	28	49	6	4	4	19	8
3	23	145	75	43	16	34	222	390	47	35	32	150	63
4	79	507	262	149	56	120	777	1364	164	123	111	524	221
5	76	488	252	143	54	116	747	1313	157	118	107	504	213
6	25	164	85	48	18	39	251	440	53	40	36	169	72
7	15	99	51	29	11	24	152	267	32	24	22	102	43
8	5	33	17	10	4	8	51	90	11	8	7	34	15
9	3	19	10	6	2	5	30	52	6	5	4	20	8
10	15	94	49	28	10	22	144	253	30	23	21	97	41
11	15	98	51	29	11	23	150	263	32	24	21	101	43
12	20	132	68	39	15	31	201	354	42	32	29	136	57
13	46	294	152	86	32	70	450	790	95	71	64	303	128
14	120	775	401	227	86	184	1186	2083	250	188	170	800	338
15	8	53	27	16	6	13	81	142	17	13	12	55	23
16&17	98	630	326	185	70	149	965	1695	203	153	138	651	275
18	58	372	192	109	41	88	569	1000	120	90	81	384	162
19	51	329	170	97	36	78	504	885	106	80	72	340	144
20	10	67	34	20	7	16	102	179	21	16	15	69	29
21	33	214	110	63	24	51	327	574	69	52	47	221	93
22	147	943	488	277	104	224	1444	2537	304	229	207	974	412
23	305	1960	1013	575	216	464	3000	5270	632	475	429	2024	856
24	47	301	156	88	33	71	461	811	97	73	66	311	132
25	27	173	89	51	19	41	264	464	56	42	38	178	75
26	43	275	142	81	30	65	421	740	89	67	60	284	120
27	94	608	314	178	67	144	930	1634	196	147	133	627	265
28	18	117	60	34	13	28	179	314	38	28	26	121	51
29	69	441	228	129	49	104	675	1185	142	107	97	455	192
30	29	186	96	55	21	44	285	501	60	45	41	192	81
31	159	1023	529	300	113	242	1566	2751	330	248	224	1056	447
32	50	323	167	95	36	76	494	868	104	78	71	333	141
33	108	697	360	204	77	165	1067	1873	225	169	153	719	304
34	59	377	195	111	42	89	577	1014	122	91	83	389	165
35	82	530	274	156	59	126	811	1425	171	128	116	547	231
36	114	732	379	215	81	174	1121	1969	236	178	160	756	320
37	30	195	101	57	22	46	299	524	63	47	43	201	85
38	75	482	249	142	53	114	738	1297	155	117	106	498	211
39	0	0	0	0	0	0	0	0	0	0	0	0	0

The matrix **F** (continued)

Sectors	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**		**Final demand consumed by labour**
1	212	115	48	552	439	285	464	425	90	467	0		6740
2	12	7	3	32	25	16	27	24	5	27	0		387
3	96	52	22	250	199	129	210	192	41	212	0		3053
4	335	182	76	874	696	452	735	673	143	740	0		10679
5	323	176	73	841	670	435	708	648	137	713	0		10277
6	108	59	24	282	225	146	237	217	46	239	0		3448
7	66	36	15	171	136	88	144	132	28	145	0		2089
8	22	12	5	57	46	30	48	44	9	49	0		702
9	13	7	3	34	27	17	28	26	5	28	0		410
10	62	34	14	162	129	84	136	125	26	137	0		1977
11	65	35	15	169	134	87	142	130	27	143	0		2059
12	87	47	20	227	181	117	191	175	37	192	0		2770
13	194	106	44	506	403	262	426	390	83	429	0		6183
14	512	279	116	1335	1063	691	1123	1028	218	1131	0		16309
15	35	19	8	91	73	47	77	70	15	77	0		1112
16&17	417	227	94	1086	865	562	914	836	177	920	0		13270
18	246	134	56	641	510	332	539	493	105	543	0		7828
19	218	118	49	567	452	293	477	437	93	480	0		6929
20	44	24	10	115	91	59	97	88	19	97	0		1403
21	141	77	32	368	293	190	310	283	60	312	0		4497
22	624	339	141	1626	1295	841	1368	1252	265	1377	0		19860
23	1296	705	293	3377	2690	1747	2841	2600	551	2861	0		41258
24	199	108	45	520	414	269	437	400	85	440	0		6346
25	114	62	26	298	237	154	250	229	49	252	0		3636
26	182	99	41	474	378	245	399	365	77	402	0		5796
27	402	218	91	1047	834	542	881	806	171	887	0		12791
28	77	42	17	201	160	104	169	155	33	170	0		2458
29	291	158	66	759	605	393	639	585	124	643	0		9278
30	123	67	28	321	256	166	270	247	52	272	0		3925
31	676	368	153	1763	1404	912	1483	1357	288	1493	0		21535
32	213	116	48	556	443	288	468	428	91	471	0		6793
33	461	251	104	1201	956	621	1010	924	196	1017	0		14667
34	249	136	56	650	517	336	546	500	106	550	0		7935
35	350	191	79	913	727	473	768	703	149	774	0		11157
36	484	263	110	1262	1005	653	1062	972	206	1069	0		15418
37	129	70	29	336	268	174	283	259	55	285	0		4106
38	319	173	72	831	662	430	699	640	136	704	0		10153
39	0	0	0	0	0	0	0	0	0	0	0		1

Appendix 7D

The Basic equation

Sectors	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	4192	0	6	17484	2014	31	22	4	2	18	9	6
2	0	0	0	0	10	0	0	0	0	0	0	0
3	30	1	260	63	97	12	9	0	0	15	126	1
4	34	0	0	2619	1325	4	0	0	56	0	0	0
5	6747	2	2	359	3910	229	16	0	0	0	63	0
6	0	0	0	0	42	154	0	0	0	0	0	0
7	2	6	0	1	0	1	350	76	0	20	7	1
8	0	0	2	2	7	1	12	118	0	1	1	6
9	0	0	0	0	0	0	1	3	72	18	0	0
10	47	4	0	9	20	15	0	0	0	298	47	5
11	22	0	8	248	557	255	35	2	7	31	724	212
12	4	0	12	151	323	213	19	9	4	34	48	3695
13	158	68	21	8	46	10	11	3	2	22	12	17
14	235	5	34	124	431	154	291	8	61	208	185	148
15	71	0	0	27	91	147	0	0	0	10	7	2
16&17	777	0	237	189	253	164	76	33	17	64	85	96
18	5	0	47	10	25	10	3	2	0	16	19	10
19	8	31	13	0	0	0	0	0	2	0	2	4
20	11	0	1	9	13	7	4	4	5	3	9	15
21	1505	0	81	194	530	85	85	11	13	74	139	115
22	369	7	70	46	111	33	27	2	3	93	65	104
23	385	3	55	45	139	53	39	16	9	78	107	58
24	13	1	6	26	59	27	19	11	5	21	23	51
25	123	1	18	42	85	15	13	1	4	15	8	35
26	0	0	17	2	6	3	1	1	1	4	8	22
27	1	56	306	20	31	15	0	2	0	9	1	127
28	183	7	58	43	96	25	25	10	10	33	35	312
29	197	0	2	24	27	5	11	4	2	7	5	20
30	179	16	6	9	16	6	4	2	3	13	14	18
31	1	0	2	46	148	24	33	42	6	89	21	113
32	917	29	277	735	1349	721	274	91	44	331	412	1225
33	8	3	8	10	15	9	5	2	1	5	3	16
34	15	3	7	20	35	14	23	5	3	5	8	122
35	26	0	7	19	31	23	8	0	0	8	19	63
36	352	0	1	0	0	0	0	0	0	0	0	0
37	2	0	2	11	22	14	0	0	0	1	1	142
38	43	4	105	97	191	111	120	29	12	47	55	155
39	5	2	18	32	60	36	12	5	0	13	19	42

The Basic equation (continued)

Sectors	**13**	**14**	**15**	**16&17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
1	6	60	11	28	9	12	6	81	50	58	123	11
2	0	0	0	0	0	0	0	0	0	0	42	0
3	334	1127	242	69	4	0	2	6477	182	32	0	0
4	0	49	0	0	0	0	0	0	0	18	815	0
5	0	249	0	1	1	1	2	0	24	30	1139	0
6	0	32	0	0	0	0	1	0	0	84	775	0
7	1	18	0	7	5	10	4	0	12	165	14	0
8	3	28	2	30	3	11	7	0	0	189	11	6
9	0	0	0	3	2	1	0	0	0	8	0	1
10	0	98	123	52	14	54	50	0	1396	184	0	0
11	8	419	52	80	75	14	36	19	29	495	11	11
12	32	280	24	204	91	67	42	17	72	2006	195	144
13	1004	1374	51	133	97	40	14	67	208	82	23	18
14	49	6433	185	600	369	468	171	79	1083	322	31	55
15	3	102	438	62	38	42	11	0	4426	142	0	10
16&17	106	566	138	7268	624	1181	197	252	4174	517	8	136
18	18	96	20	405	1184	994	59	180	623	233	17	40
19	4	14	2	159	6	1715	11	2	64	71	0	232
20	14	51	8	86	81	89	120	50	86	272	11	39
21	83	958	258	920	246	128	81	1690	165	1191	504	170
22	55	312	81	343	100	55	25	46	17387	506	166	62
23	90	337	90	390	116	73	39	59	373	3433	46	85
24	31	186	24	198	118	66	27	12	34	710	343	102
25	7	51	29	59	44	33	18	45	589	975	55	185
26	5	35	7	29	23	17	6	2	14	320	0	0
27	48	102	9	92	52	43	9	3	227	457	11	32
28	40	200	32	218	135	60	36	150	168	1675	117	83
29	2	42	10	50	16	15	4	24	158	932	40	18
30	3	32	10	60	10	20	7	2	80	457	172	101
31	82	184	113	258	61	97	50	0	487	3130	566	373
32	698	2506	513	2142	1203	806	250	192	2491	5162	960	509
33	7	31	3	21	19	15	4	1	32	98	19	10
34	34	80	10	61	37	33	30	502	52	201	65	9
35	74	200	21	102	145	37	9	30	26	126	33	11
36	0	0	0	1	0	0	16	3	0	0	0	0
37	7	28	1	17	14	6	0	3	4	147	2	0
38	149	557	94	373	286	132	46	144	276	677	162	138
39	17	108	22	83	43	20	9	32	134	654	78	25

The Basic equation (continued)

Sectors	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**
1	50	77	7	13	5	72	6	5	127	1	64	46
2	0	0	0	0	0	0	0	0	0	0	9	2
3	0	0	0	0	0	0	0	12	49	0	0	0
4	61	0	0	0	0	0	0	16	8	4	215	59
5	55	0	1	0	0	0	0	110	62	4	246	161
6	9	0	0	0	0	0	0	63	34	3	19	208
7	1	0	0	0	1	0	26	10	12	8	21	10
8	8	23	0	0	0	0	6	1	3	0	10	2
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	40	0	4	3	102	28	12	19	7	0	6
11	12	30	26	19	7	6	78	41	28	26	48	14
12	51	179	124	330	130	9	2915	397	225	386	160	89
13	317	345	28	14	14	8	73	137	102	57	25	58
14	12	38	7	12	5	44	193	129	67	48	408	32
15	0	2	0	0	0	105	0	27	53	8	7	10
16&17	54	361	96	78	56	80	192	326	195	54	36	8
18	80	59	87	77	27	174	75	509	109	50	45	67
19	120	188	3	9	5	0	9	734	11	0	7	0
20	30	47	13	28	18	41	100	31	95	27	121	20
21	37	431	46	156	81	70	264	227	359	327	399	286
22	146	828	1040	378	193	2996	206	1329	1868	427	223	181
23	110	313	54	161	103	449	438	246	127	58	91	52
24	37	136	45	147	117	6	923	307	118	36	130	190
25	13	936	20	171	132	0	668	68	56	49	46	55
26	767	41	46	19	8	0	22	35	6	2	5	7
27	551	1701	77	109	66	1	121	359	135	52	55	51
28	146	428	153	1550	200	71	772	502	263	147	326	567
29	23	42	0	180	742	0	116	287	436	4	0	49
30	18	147	1	66	3521	187	227	62	23	26	48	36
31	8	343	129	387	84	148	1150	353	388	92	345	148
32	270	1642	360	1314	454	805	6575	1823	590	499	707	1027
33	1	14	7	4	114	9	47	644	78	0	39	48
34	11	133	60	65	28	273	128	51	234	1284	78	236
35	0	25	6	11	11	22	78	184	97	101	107	36
36	7	20	2	0	62	0	0	185	85	125	680	10
37	13	26	0	112	44	0	483	319	207	53	38	1143
38	76	566	311	232	170	97	404	1234	739	536	1110	362
39	10	33	23	23	4	26	181	0	0	1	30	10

The Basic equation (continued)

Sectors	**38**	**39**	**Residual final demand**	**TOTAL**	**Proportional total output**	**Redundant output**
1	60	34	15936	**40744**	40370	374
2	8	0	916	**987**	959	28
3	3	0	7218	**16364**	16057	307
4	196	100	25250	**30827**	30017	810
5	206	219	24299	**38136**	37613	523
6	34	124	8153	**9735**	9505	230
7	7	4	4939	**5737**	5558	179
8	20	0	1660	**2171**	2113	58
9	0	1	969	**1080**	1045	35
10	49	87	4675	**7447**	7303	144
11	40	1	4867	**8593**	8390	203
12	237	3	6550	**19471**	19141	330
13	95	0	14621	**19380**	18784	597
14	357	27	38562	**51670**	50188	1482
15	14	0	2629	**8483**	8453	30
16&17	89	9	31377	**50169**	48890	1279
18	50	17	18508	**23951**	23214	737
19	27	0	16382	**19834**	19182	652
20	49	17	3316	**4943**	4819	123
21	665	0	10634	**23207**	22849	357
22	291	0	46960	**77131**	75585	1546
23	89	3	97555	**105967**	102724	3244
24	148	0	15006	**19456**	18909	547
25	102	0	8598	**13361**	13039	322
26	6	0	13704	**15190**	14723	467
27	132	0	30244	**35305**	34202	1104
28	290	0	5812	**14978**	14709	269
29	31	0	21938	**25461**	24747	714
30	83	0	9279	**14962**	14782	180
31	782	0	50919	**61203**	59498	1705
32	1446	0	16063	**57415**	56399	1016
33	36	2	34680	**36068**	34895	1174
34	110	0	18762	**22826**	22174	653
35	232	0	26380	**28307**	27408	899
36	68	0	36456	**38072**	36876	1196
37	65	48	9709	**12681**	12312	369
38	930	0	24006	**34772**	33864	908
39	49	0	2	**1857**	1857	0
Total				**997943**	**973151**	
Loss				-2,68%	-5,10%	

Appendix 7E

An Example of Data Coupling in GIS

A short example of how the above flowchart and use of data is applied in practice may clarify the way we deal with our data. Let's take a simplified input-output table for a small economy. This economy consists of two sectors: A and B. Besides this we have data on imports and on other final demand. We start with the following data (Table 7E.1):

To **From**	**A**	**B**	**Housholds**	**Other final Demand**	**Gross output**
A	20	45	30	5	100
B	40	15	30	65	150
Households	20	60	10	10	100
Imports	20	30	30	0	80
Gross outlay	100	150	100	80	430

Table 7E.1. *Example of a transactions table*

Suppose, in addition, we also have a database that contains data on the location and on the intensity (number of workers) of economic activities. In this environment we can perform operations that allow us to deal with the spatial character of the data. One of the first operations we can implement with a GIS is to give thematic data exact geo-location. In our example, this is done by linking the thematic data on economic activities to a geo-referenced database using zip codes (in this small example, we keep the X and Y coordinate fields empty; of course, in the real GIS environment they are filled in).

Suppose that from our overlay operation, we find that the areas containing zip code "9977 AB" and zip code "9978 ZK" are flooded (we have lightly shaded them in Table 7E.2). This would mean that these activities would seize to function for some time. The database is supposed to contain all information on all activities; this means that now we can make estimates of the impacts of a disruption on each sector. In our example this means that we can summarize this impact in the following table.

	X	**Y**	**Zipcode**	**SIC-code**	**SBI-code**	**Z value (number of workers)**
1			9976 KJ	8844	8	9
2			9976 KJ	8845	8	3
3			9977 AB	8849	8	0
4			9977 AB	8850	8	2
5			9978 XZ	6670	6	10
6			9978 XZ	6671	6	5
7			9978 ZK	6675	6	4

***Table 7E.2**. Example of how a GIS-database might looks like*

The end result of this operation is an estimate of the effect of a natural disaster on the economy. This fraction of lost employment will be used to model the impact of the shock on the economy (Table 7E.3).

SBI-code (sector)	**Number of workers affected**	**Number of workers in the affected area**	**Fraction**	**Percentage capacity loss**
8 = A	2	14	2/14	14%
6 = B	4	19	4/19	21%

***Table 7E.3**. Calculation of loss of output*

Chapter 8

Water and Flood Management in the Netherlands: Shifts in Policy and Modelling

8.1. INTRODUCTION[88]

One of the most rewarding cases to consider in conjunction with our methodology to analyse the consequences of major disruptions in modern economies is the issue of flooding and flood management in the Netherlands. In the European spectrum of countries, the Netherlands occupies a special place. For centuries, water management in the Netherlands was subject to smart solutions in the engineering sphere – constructing complex system of dikes, drainage systems and artificial canals,[89] which resulted in a highly-developed country with high potential, partially occupying the land conquered from water. It is due to this amazing fight against nature that the Dutch have become world-renowned experts in water management, dike and levee construction.

For the Netherlands as a low-lying country, a major flooding can be highly destructive, if not catastrophic. This is a consequence of the country's location on the coast of the North Sea, with almost half of its territory below sea level. As it is in the downstream of three biggest rivers in Europe, the Rhine, the Meuse and the Scheldt, the Netherlands face a constant danger both from the rivers and the sea. Being under pressure of the uncertain dynamics of possible climate change, there are the implications to deal with, i.e., the rising sea level and increasing extreme fluctuations in peak flows, which are increasingly acknowledged by various experts (*inter alia*, MNP, 2005). It is important that flood protection is recognised as a crucial policy issue. Recent findings of a predicted increase of extreme precipitation events and a gradually subsiding ground level in the Western (coastal) parts of the country further intensify this. Learning to live with risks, and adapting accordingly, means that we have to look far ahead when making today's choices.

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[88] This Chapter is largely inspired by a paper Bočkarjova, Steenge and Hoekstra (to appear 2007) "Management of Catastrophes: A Paradigm Shift in Thinking about Flood Risk" In: Folmer and Reinhard (Eds.) "*Water Problems and Water Policies in the Netherlands*".

[89] Currently primary and secondary dikes are protecting the country where each has its own role. Primary dikes are the ones built along the coast and along the main rivers. Secondary dikes are limiting the artificial water reservoirs and canals. By pumping excessive water back to the rivers and the sea, the water level in these artificial storages can be regulated.

In this Chapter, specific aspects of recent thinking about the consequences of big floods are discussed. Economic development and population growth in the Netherlands in the past decades, together with changing natural conditions caused by climate change, trigger shifts in the approach towards water management and threats of a major flood. It appears that the risk of such floods occurring has steadily increased in the past decades, which implies that traditional, technology-based approaches (such as raising the dikes) can no longer be seen as a single remedy. This means that more integrative approaches are asked for, and thus become central to our discussion in this Chapter.

The Chapter focuses on policy options in cases where, due to a catastrophic flood, part of the existing economic networks fails for a considerable period and many supply-demand relations are disrupted. The economy suddenly has to decide on how its now restricted resources should be allocated. Following our modelling logic, set forth in Chapter 6 of this thesis, we choose an approach which offers a suitable instrument for analysing alternative policies which (re)direct the circulation of available resources between various categories of sources (‘suppliers’) and destinations (‘buyers’) in an intelligent way. In fact, the case of potential major flooding in the Netherlands should be considered with due care, where mixed mechanisms of public policy and private response must take place. This is important in particular due to the recent developments in water and flood management in the Netherlands, which point to newly emerging underlying principles in public policy, namely in the direction of shifting the balances between the public and private domains in favour of a more involved model of sharing responsibility. From this, it becomes clear that the problem then becomes a matter of complex interactions between private and public interest. For this purpose, our input-output model for disaster analysis (see Chapter 6) can provide sufficient flexibility to address policy issues for a country facing a potential threat of a major flooding, covering both *ex ante* adaptive measures and measures structuring recovery in the immediate disaster aftermath.

This Chapter is arranged as follows. First, we start with a brief historical retrospect, leading up to contemporary water and flood governance structures with the changing demarcation between individual and state responsibility. Next, we will provide some insight into the current Dutch policy dynamics that seem to resemble self-reinforcing mechanisms. We shall draw attention to the critical position at the moment for choosing the time horizon and taking decisions for future development trajectories; some main lines will become clear, but by and large, the debate is just beginning. Finally, we will show that our methodology for modelling economic aspects of major disturbances can be used as a tool for addressing current issues in Dutch policy-making while fitting into the European trend of giving more attention to flood protection issues.

8.2. THE NETHERLANDS: FROM FIGHTING AGAINST WATER TO LIVING WITH WATER

The Netherlands makes a suitable case of reference in our study of major disasters in the developed countries. With the population density four times EU average (480 inhabitants per km^2 in the Netherlands against 117 in the EU-25, 2003[90]), the country

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[90] Source: Eurostat (www.europa.eu.int/comm/eurostat/). For comparison, population density in Germany is 230 inhabitants per km^2, in Latvia – 37.

has an extensive industrial network, which can be adversely affected as result of a disturbance. In this Section, we shall address the Dutch ‘philosophy’ with regard to water management. Here, the trend of seeing the water as an enemy seems to give way to a major change in thinking, i.e. an approach based on the principle of living together with water. This means that different ways of thinking on flood protection and the entire water management in the country become necessary. We shall first provide some historical background, and then turn to the recent developments in Dutch policy-making, illustrating the shift in thinking on water management and flood protection.

8.2.1. Short Overview of Flooding Disaster History in the Netherlands

The Netherlands has witnessed a number of water-related disasters in its history. Many people still remember the terrifying flood of 1953, which however was not the first disaster that the country has ever witnessed. Major calamities are recorded from as early as 838[91]: the first floods (838 and 1014), St. Elizabeth’s floods (1404 and 1421), all Saints flood (1570), Christmas flood (1717) and the Zuiderzee flood (1916). One of the more recent experiences, although it did not lead to a devastating calamity, is the near-flood event of 1995 when 200.000 people were evacuated because a polder along the river Rhine was in danger of being inundated.

One can consider the Zuiderzee flood as a warning coming before the major disaster of 1953, signalling the existence at that time of weak points in the coastal protection belt. As a response to the 1916 flood, the construction of the so-called ‘Afsluitdijk’ was initiated, which cut off the ‘Zuiderzee’, which then became an interior lake, the ‘IJsselmeer’. This was combined with other large infrastructural works such as the elevation of two new polders, ‘Wieringermeer’ and ‘Noordoostpolder’, which added new farmers’ land and connected several islands to the mainland. In later years, two more polders were added, carved out of the IJsselmeer, ‘Oostelijk Flevoland’ and ‘Zuidelijk Flevoland’, which combined different functions, providing room for new towns, farming, nature and recreation.

However, the Afsluitdijk, connecting the provinces of North Holland and Friesland, could not prevent the disaster of 1 February 1953, when the provinces of South Holland and Zealand were thoroughly flooded. Apart from the poor condition of the many dikes in the Delta area, the flood was largely due to an unfortunate combination of climatic circumstances. Starting 30 January 1953, during the period of high tide, a strong depression had formed to the North-West of the Netherlands, moving towards the country. The hurricane that emerged in that depression area intensified the high tide, existing at that time, and caused the collapse of the weakened protective dikes in the early morning of 1 February. The highest recorded water level was reached: 4,55 metres above NAP (Normal Amsterdam Water Level). A further second flood during 1 February worsened the situation, claiming more lives, as the dikes were breached, giving the water every opportunity to further inundate the low land.

The consequences of the flood were terrifying. 1.835 people died as a direct consequence of the flood, about 40 more people died afterwards. 200.000 cows, horses, pigs, and other cattle died in the water and almost 200.000 hectares of land were flooded. The contamination by the salty water meant that the once fertile soil was

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[91] Source: Delta Works online (www.deltawerken.com)

unusable for many years. 3.000 houses and 300 farms were destroyed and another 40.000 houses and 3000 farms damaged. 72.000 people had to leave their houses and were evacuated to other areas. Only by the end of 1953, the area was officially declared dry again.

This enormous flood triggered the emergence of the 'Delta Plan', a combined strategy of a) building higher dikes, and b) developing the entire delta area. The resulted execution of Delta works – the impressive construction of an open dam consisting of a system of 62 massive sluices, cutting off the major outlets to the sea (with the exception of the Scheldt, motivated by the interests of Antwerp harbour), was concluded in 1997 with the building of the movable storm surge 'Maeslant Barrier' near Rotterdam, which can close off the New Waterway when water levels rise to a threatening level. All these works were carried out as the country's immense investment in the protection against future floods. However, currently – half a century after the last disaster –the Netherlands is facing new challenges.

8.2.2. Marking the Shift from Probability to Risk Management

From the short overview of the flood history of the country in the previous Section, we note that the policy of guaranteeing public safety in the Netherlands by raising and strengthening the dikes in combination with land claim policies has an extensive record. It reached its culmination in the Delta Plan, after the 1953 flood.[92] The decisions made in that context fixed Dutch policy for the next 50 years. The political pressure in the aftermath of the 1953 tragedy was triggered by public belief and expectations that the government will provide protection against flooding in the future. Due to the technical infeasibility at the time to conduct a detailed study of economic vulnerability, as well as the inability to anticipate the extent of growth that the country would witness in the coming decades, the 'Wise Men' of the Delta Commission concentrated on solutions targeting the probability of flood to be reduced to close to zero. This has resulted only in a partial safety standard differentiation according to the relative economic importance of the areas in the design of the Plan. The main focus was to ensure safety under the motto "never again such a flood". The Delta Commission asked Van Dantzig, a well-known statistician, to address the problem of calculating the optimal investment strategy in flood protection. He developed a general formula for the optimal size of flood protection measures, the dikes, in a dynamic context, where investments at regular intervals are required. His formula gives a fixed exceedance probability[93] after each investment in the relevant safety structure. The method is still in use in the cost-benefit analysis of flood-protection measures today.

The high standards applied in flood defence constructions thereafter (like water overtopping a dike once in 10.000 years in the utmost for the most vulnerable areas in the Western part of the country) created a general feeling of security, and reinforced the expectation that public authorities can always guarantee safety, both of which reflected a near absolute faith in the physical, geographical and climatological foundations of the underlying (model) calculations. This permitted an accelerating socio-economic

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[92] The first comprehensive study of the Delta Plan was presented by Maris (1954), Tinbergen (1954) and Zeegers (1954), and discussed the engineering, economic, and social aspects of the plan.

[93] The term exceedance probability refers to the chance that water level exceeds the top of the dike, resulting in overflow and breaking of the dike and thus flooding of the land behind the dike.

development behind the dike system in the subsequent decades. The protected areas rapidly changed into a highly urbanized economy, claiming a significant role in the 'global village' of international commercial and social networks. The fact that human and economic interests behind the dikes became higher and higher slowly created a problem in itself. What was not sufficiently realised at the time, was that the protective system and what that system is protecting are bound together in a seemingly endless feedback system with ever increasing stakes and potential damage. Thus, policy mainly focusing at managing the probability of flooding meant that less attention was paid to measures controlling and reducing the consequences of a potential flooding. This resulted in a situation when the *risk of a flood*, defined as the product of the probability of a flood and the expected loss in case of a flood, was addressed one-sidedly by looking only at the first term of the risk equation, which is not sufficient for reaching a long-term solution.

At the same time, it gradually became apparent that the state can not completely control natural variability or changes therein – which means that extreme situations will always remain possible. The fact that flooding frequency standards during the past fifty years did not change and that economic expansion behind the dikes was exponential actually increased expected risks (RIVM, 2004). That is, although the probability of flooding is relatively low at present, potential damage is enormous. Against this background, there is a developing insight that the current strategy cannot be sustained *ad infinitum*, and that new solutions have to be found (see e.g. Commissie Waterbeheer 21e Eeuw, 2000).

A corresponding development in this context is the growing importance of system risk analysis (see e.g., OECD, 2003; Dalziell and McManus, 2004). Characteristic for the system approach is that it considers a system in its entirety, which, as opposed to partial analysis approaches, is considered to be 'bigger than the sum of its constituents'. For us it is interesting to consider that part of system analysis that studies the effects of positive and negative feedbacks (Hoekstra, 2005). In this context, a positive feedback is the mechanism that favours the reinforcement of the initial impulse; a negative feedback, on the contrary, suppresses the impulse. This means that negative feedback mechanisms are necessary for a system to stabilise itself. This approach, applied to water and flood risk management in the Netherlands can imply that in particular negative feedback mechanisms are of crucial importance to be built in, to ensure that the country is able to deal with a hazard without incurring extensive damages, and be flexible enough to adjust to the new circumstances. In this way, negative feedback resembles features that come very close to the ideas of resilience and adaptability that we discussed in Chapter 2. We put forth that adapting in advance to potential adversities, thereby decreasing vulnerability and improving the resilient response capacity of a system, improves the systems' persistence in the face of a disaster. If system risks pose a threat to the stability of a social system in its entirety, then relevant questions for the Netherlands are the following: Which combination of technical, economic, financial, legal and administrative policies and/or measures can contribute to improved risk control, and in particular to decreasing the economic and social vulnerability to flooding? New insights *inter alia* into the economics of a calamity in the context of a modern developed economy are then also required.[94]

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[94] Here we shall not discuss related developments such as the establishment of modern systems for data storage and retrieval in water monitoring. However, we should mention the recently developed High-water Information System in the Netherlands (MTP, 2005a). This system is designed to monitor flood defences, to present inundation calculations and loss calculation as a decision-making support tool for

A number of elements in the process of growing awareness in the Netherlands can be detected. One of the first issues which has been realised is that risk analysis is not (only) about the probability of a certain water level of the rivers or sea to reach some critical value as it used to be, but also about the probability that a particular link in the entire line of defence construction succumbs (TAW, 2000; Vrijling, 2001). That is, one should be looking for possible dike failure mechanisms,[95] stability of dike closing mechanisms (like sluices) and, more generally, for the weakest links in the entire protective system. The real probability of a flood is therefore equal to the probability of the water reaching a particular level in conjunction with other failure processes.

Today the country has reached the conclusion that it has gradually ended up in a self-reinforcing state with potentially catastrophic consequences. The conclusion has emerged that not only decreasing the probability of a flooding should be considered, but also (and specifically) the possible consequences of a flood. According to the recent RIVM report "Dutch dikes and risk hikes, a thematic policy evaluation of risks of flooding in the Netherlands" (RIVM, 2004), at present the Netherlands is not adequately protected against the threat of flooding, both from the sea and the rivers. The following quote clarifies the statement (*ibid*, p.12): "Dams in the Netherlands have never been stronger. […] Yet the risks of causalities and economic damage have become much greater [since 1953]." The new question in this respect has become: How to balance lowering the probability of a flood *and* lowering the potential damage. This means an entirely different conceptual basis, reflecting the shift in Dutch thinking and policy-making about protection strategies, which may be referred to as a shift in paradigm (see Bočkarjova, Steenge and Hoekstra, 2007). The concept of risk is being re-discovered, and this nowadays becomes the key to understanding the future direction of water policy in the Netherlands. Furthermore, the report signals a discrepancy between the legal standards regarding dike height and socio-economic growth in the past decades. The main conclusion of the RIVM study is (2004, p.13): "The current safety policy does not create the conditions for the Netherlands that would lead to the safe and suitable for habitation country as it has been provided by the determination of the safety standards of 1960. […] The safety standards are no longer cost effective with regard to the spatial distribution of the economic assets. […] Economic values and the lives of people are less protected than it has been provided in 1960". The report claims that it is not about the dikes, i.e. the technological response to the threat of flood. What is required are spatial solutions as the dynamics of economic asset accumulation as well as human settlements have been overlooked for decades by the former generation of planners. These are the standards for future developments in the economy, not the standards of today which can be viewed as a threshold for the drawing up and the implementation of current protection paths.

The second study to be mentioned in conjunction with the marked shift in policy perspective is "Flood Risks and Safety in the Netherlands" (MTP, 2005d), a study initiated by the Ministry of Transport, Public Works and Water Management. It focuses on safety within the Dutch system of interconnected polders (we shall return to this issue in the next Section). This presented a series of calculations based on an adapted

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officials in charge. Several stakeholder organisations are involved, with a central role for the Dutch Ministry of Transport, Public Works and Water Management.

[95] Nine dike failure mechanisms are distinguished (RIVM, 2004 p.110): overtopping; instability through infiltration and erosion after overtopping; piping; heave; macro-instability at land side; macro-instability at river side; micro-instability; instability of dike cover; and sliding off at riverside.

framework in which not only dike overtopping was accounted for, but also several other causes for dike breaching (see footnote 95 as well as Section 4.2.1 in Chapter 4 for the description of modelling methods).

One can see from the description of reports above that the noted awareness causes a gradual shift in thinking about water policy, with increasing attention being paid to the possible *effects* of flooding and to measures to prepare the country for the new (and changing) circumstances. In this context, new ideas such as ‘room for water’ or ‘room for the river’ fit in extremely well (Silva, Klijn and Dijkman, 2001), as well as new views on concepts like vulnerability and resilience (discussed in Chapter 2). Also, the idea of minimizing system risks within system approach, which we briefly mentioned earlier in this Section, fits in well. The new concepts in contemporary Dutch water management ‘room for water’ and ‘room for river’ (also sometimes referred to as ‘letting the river be the river’ in Linnerooth-Bayer and Amendola, 2003) refer to the proposed approach of giving more space to natural water flows instead of building water defences and thus making the water flow in modified ways. In particular, the ‘room for river’ approach suggests that, with the aim of managing floods and improvement of overall environmental conditions, river cross sections are widened by situating the dikes further away from the river, or by lowering the river forelands. It is also possible that in some cases retention areas are assigned for controlled flooding in case of extreme water levels to avoid uncontrolled dike breaches or overtopping. This is expected to result in lower flood levels; for example, by the year 2015 the river Rhine should be able to safely discharge 16.000 m^3/s, and by the end of the century 18.000 m^3/s (with a current capacity of 14.000 m^3/s).[96] Implying a new kind of approach to flood management, ‘room for water’ requires new spatial planning and consequently also new ways of decision-making. This essentially has to do with the selection of the locations where more room would be given to the natural flow of the rivers and where arrangements would be made with people affected by the new approach. Because the population is actively involved in the decision making processes, practice has proven that communication on the part of the government and local authorities, on the purposes of the new measures, plays an essential role in achieving societal consensus (RIVM, 2003, p.14).

Other reports, “National Spatial Strategy” (MHSPE *et al.*, 2004) and “Peaks in the Delta” (MEA, 2004), were published by the government, marking the further change in thinking about water. In addition to the new strategy of protection against floods, being implemented, a new spatial planning is under way involving many more interested parties, which can ultimately change the pattern of future human activity distribution. This presumes integration between spatial planning, economic development and water management, as the ‘room for water’ strategy means the creation of detention areas available for controlled inundation in case it becomes necessary to control exceptional water flows. Such an approach will evidently demand a revision of spatial patterns for land use, and can cause adjustments resulting in changing economic (infra-)structure in the long run. A number of studies have been initiated to support anticipated new directions in water policy and management in the Netherlands (such as an ongoing research in the field of climate change, in particular the ‘Climate Changes Spatial

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[96] For more information, see the website of the project “Room for the River”, www.ruimtevoorderivier.nl.

Planning' research project covering five main themes: climate scenario's, mitigation, adaptation, integration and communication can be mentioned).[97]

However, the arguments outlined in this Section only provide a snapshot of wider public, political and academic discussions going on in the Netherlands. A shift in attitude to flood protection from a static, probability-oriented approach to a more integrative risk management can be seen (see also Bouma, Francois and Troch, 2005). Still, it is to be expected that it will take some time before the new approach becomes an accepted 'business-as-usual' practice. At the moment, studies of multiple flooding effects, their interdependence and repercussions through time, have to be conducted before specific policy decisions are taken and measures are implemented which can have a massive influence on the future development paths of the country.

8.2.3. Risk Management Approach

Observing recent developments on the issue of flood protection in the Netherlands, we note the revival of the concept of risk in flood management. Risk is the product of the probability of flooding, and its consequences (i.e. the costs inflicted). If we denote the flooding probability by the symbol P, and the expected effect (i.e. the potential economic consequences) by E, the risk R can be defined as $R = P \times E$. Acknowledging the fact that the full flood risk is the sum of different flood scenarios, it is more precise to write: $R = \Sigma_i (P_i \times E_i)$, where $i = 1$ to n denotes the number of flood scenarios. For many years, public policy was aimed at lowering P as much as possible. Simultaneously, however, as we mentioned in the previous Section, the country experienced a period of rapid growth, which meant that E, the potential flood effects, in the risk formula became larger and larger. This has lead to the situation where, at the moment, the Netherlands is confronted with the exceptionally low probability of a flood (by age-old philosophy) and potentially extremely high consequences. In order to bridge this discrepancy in the coming decades, the risk approach must be translated into a policy aiming at decreasing overall risk. This is evidently a formidable task, because it not only requires insight in the 'risk equation' and its dynamics, but also in the relationship between the two terms comprising risk. This clearly is the place where the water management specialist and the social scientist meet.

The discussion in the previous Section, as we have seen, clearly signals what one may call a 'paradigm shift' in water and flood management in the Netherlands. That is, a shift from focusing on the probability of a flooding to thinking in terms of risk of a flooding, which opens a much broader setting for problem analysis and policy decision-making. The essence of the 'old' thinking in this sense is keeping the probability of flooding constant in conformity with the accepted standards (for example, those laid down in the law). The 'new' thinking takes into account the risk connected to the event of a flood, which means a balanced attention to both flooding probabilities and effects. A further step in this direction would focus the attention of politicians and decision-makers at managing in particular the potential effect of a flooding, because flooding probabilities in the Netherlands are already very low. The background here is that the accumulation of assets and the accelerated urbanisation in the flood-prone areas of the Netherlands dictate 'new rules of the game'. The probabilities of a flood set out in the

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[97] See the website of the project 'Climate Changes Spatial Planning' for more information: www.klimaatvoorruimte.nl.

National Flood Defence Act (1996) are actually miniscule, especially in comparison with the standards imposed around the globe, averaging once per 100 years. This means that to some people, further efforts at a reduction of flood probabilities in the Netherlands may make little sense. Therefore, management of the effects of a flood becomes indispensable as a main direction for future policy developments.

The recent discussions about the need to reconsider current flood risk policy reactivate the issue of equality in protection levels. The question is whether everyone, wherever (s)he lives, has a right to the same protection level, or that protection levels should be a function of population and capital densities per dike ring. In the former case the safety level in each dike-ring area should be of the same order of magnitude. In the latter case (reflecting the current situation) one is in fact forced to accept different safety levels in different polders. With the state financing water safety, as is the case now, probably no difference would be observed. However, if the state opts for a responsibility-sharing model, involving more participation on the part of the public in water management decision-making, as shared financial responsibility, the final choice of staying in a higher risk area would be up to the people living there. Also, because of differences in economic growth rates, currently existing demographic and economic differences can become more prominent in the medium and long run. In fact, the very principle of thinking about floods in terms of risk implies also that in future the ultimate decision about the acceptable level of risk should be made by society at large. That is, flood protection should no longer be a sole matter of engineering, but rather be decided in public debate and compromise. This requires that many parties become involved in the negotiating and decision-making processes in the future.

Bouwer and Vellinga (2007, pp481-482) contribute to this discussion, arguing in a similar manner: "The Dutch policy with regard to the safety levels and the protection against floods needs to be reconsidered. More than before, the potential impact of a flood needs to be the starting point for decisions. […] The idea that the land has to be protected at all costs could also become an issue for debate and safety levels in some area could be lowered." This means that it is increasingly realised that, apart from looking at probabilities connected to a flood event, also potential consequences have to be taken into account, which in turn leads to reconsideration of protection standards and rules. We should add that increasingly, analyses of the social, environmental and economic costs and benefits are required to determine the most cost-effective measures which would correspond to the accepted level of risk connected with a major flooding event. Options to be considered include increasing dike heights, but also providing more room for the rivers, compartmentalising existing dike rings, creating emergency inundation (retention) areas, adjustments in building methods, rearranging spatial patterns of living and economic activity in the long run, *et cetera*. One of the implications for the developing shift in perspective is that it is increasingly more important to properly account for the economic consequences of any particular decision, as the country (now) has to weigh investments in extra safety against the costs of a possible flooding. This means that on the economic side, cost benefit analysis will be a central element, combined with willingness to pay studies to explore the opportunities for alternative solutions that would in turn lead to the emergence of a more sustainable and risk-aware society.

An important issue in the ongoing debate is the responsibility issue. Up to now the Dutch government has had full responsibility for all of the water-related risks, at least as perceived by the public. The question is if this can continue in the future. One aspect is that no government can guarantee perfect safety from natural hazard; residual risks will always remain. Recently, in the Netherlands the question appears how to cover this residual risk. Public or private initiatives, as well as mixed solutions will have to be found. In the light of this discussion, one notes an intensification of the debate on private insurance against flooding both in academic and public circles (see Chapter 3, Section 3.2.4), as well as research conducted at the Institute for Environmental Studies (IVM) at the Free University of Amsterdam, *inter alia* Botzen and Van den Bergh (2006a,b).[98] We shall elaborate this issue in the next Section.

Addressing this issue immediately touches upon the (future) scope of governance, which brings entirely new elements into the discussion. For example, Ahrens and Rudolph (2006), point to the interdependence between governance structure and a country's susceptibility to hazards, and risk reduction, where accountability, participation, predictability and transparency play an important role. In any case, the role of the Dutch Water Boards, the age-old public bodies governing water safety on the local level, can be reconsidered as well (see also Kuks, 2004). Water Boards in the Netherlands are fulfilling three tasks: i) water control, including protection against flooding by means of dunes, dykes and canals; ii) water management including both water quantity and quality; and iii) management of inland waterways and roads (see Unie van Waterschappen, 2004). Recent reports point out the potential for an increasing importance of Water Boards to sustain flood risk management in the future. For example, the report of the Advising Committee on the Financing of Primary Flood Defences (Vellinga *et al.,* 2006), Dutch Water Boards are suggested to have higher financial capacity in the long run compared to the current model of financing stemming from the national budget to guarantee sufficient investments in the improvement of dike rings. There are three main reasons underlying this conclusion. First, Water Boards in the Netherlands already have a long history of successful water management and self-financing. Second, they are independent of state, and therefore are not subject to political changes or compromise. Finally, because of the expected increase in investments in primary defences (among others, connected to the pressured put by the climate change, as well as underinvestment in the last decades), higher tax burden has to be put on the public; yet it appears that people would rather accept water board tax increase than a national tax increase, which should ensure the solvency of the Water Boards in the longer term. The next Section will follow up on the topic of the reshuffling of the balance between public and private domains.

8.2.4. The Emergence of New Public - Private Balances

For a long time, responsibility for flood protection in the Netherlands has rested solely with the government. However, as pointed out, recently one notes a shift in opinion towards more interactive decision making, involving more parties. Lately, the government has started to express its views on a more deregulated mode of dealing with flood risks. The National Policy Agreement on Water (2003) puts forth that issues concerning protection from and reaction to calamities should be addressed at the level where they appear. This principle, in practice, should mean that individuals, municipalities and provinces should show more initiative in taking care of their own safety without relying solely on the protection provided by the national government. This is supported by the views proposing a shift of the current mode of government

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[98] More information can be found on the IVM website www.vu.nl/ivm.

responsibility to a model of shared responsibility (Wouters, 2000a,b). Here, in the context of the transition in Dutch water management from 'keeping water behind the dikes' to 'living with water'[99], people have to learn how to deal with risks connected to flooding, as well as taking more responsibility. Among others, this can be seen as adjustments in building modes and standards, location choices for residential and business areas, and cooperation between various actors within society.

This is a remarkable development, marking another shift in the approach to flood risk. Up to now, flood prevention has been often seen as a public good. The observed shift signals a change in the non-excludability characteristic of a public good. That is, the producer of the good (the national government) may (gradually) introduce a policy of excluding particular parties from consuming this, for example, as it is the case with the introduction of the so-called 'unprotected areas' or areas located outside the dikes (in Dutch, '*buitendijkse gebieden*'), see MTP (2002, 2005b). To clarify, in contrast to the protection standards for dike rings defined by the Flood Defence Act (1996), 'unprotected areas' are not incorporated in the Act, and are in fact those areas found just before or on the protective dam or dike. In the province of Flevoland, the ports of Urk, Lelystad, Almere and Zeewolde fall under the defined 'outside-the-dike areas'; on the coast, 13 such areas are identified, among others the famous places of Vlissingen, Scheveningen (near the Hague), Katwijk, Noordwijk, Zandvoort and Friesian islands in the Wadden Sea. Here, an attempt is made to prevent future development that runs the risk of erosion during storm surges (MTP, 2002). Yet there is no clarity about the protection level that the government can offer to the existing infrastructure and people living in these outside-the-dike areas. A special commission, the Poelmann Commission, was appointed to advise the Undersecretary of the Dutch Ministry of Transport, Public Works and Water Management on the further development, protection level and responsibility for protection in the areas located outside the dikes. Its report (Commissie Poelmann, 2005) revealed that protection and development of these areas should be closely considered as a specific case in flood protection.[100] We therefore observe here a tendency to growing institutional diversity, attributing more direct influence and responsibility to the parties involved.[101]

Insurance

One of the points, which reappears in our discussion of public-private balances, concerns the issue of insurance against flood. We have put forth the main line of the discussion on this issue in Chapter 3, outlining its basic principles as well as the problems related to insuring low –probability – high consequence events. In the case of the Netherlands, this has its own implications, as apparently the issue of flood event insurance is problematic on the part of insurers, as well as on the part of the population,

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[99] See also the website of the promoted policy of "the Netherlands lives with water" www.nederlandleeftmetwater.nl.

[100] For more information concerning 'unprotected areas' ('*buitendijkse gebieden*'), see the websites of the online Knowlegde Centre "External Safety" http://www.externe-veiligheid.nl and STOWA (Dutch abbreviation for *Stichting Toegepast Onderzoek Waterbeheer* - Foundation for Applied Research on Water Management) http://www.stowa.nl/.

[101] This may be interpreted in terms of a Williamson alignment (re)arrangement in which governance structure and product (or transaction) are aligned in such a way that total transaction costs are minimized (Williamson, 2000). Transaction costs, then, are interpreted in a broad sense, including information, bargaining and monitoring costs.

both individuals and businesses. On the part of the insurers, at the moment private insurance against flooding is not available in this country. This has historical grounds, going back to the flood of 1953. After this disaster, insurers basically refrained from selling policies covering flood damage, arguing that flood risk is an ‘uninsurable catastrophic risk’ (see Kok, 2004 and 2005). However, recently the issue of private insurance is increasingly addressed. Herein lies a fundamental problem, however. As mentioned in Chapter 3, insurance is based on diversification and generally covers events with a known frequency distribution. However, a disaster, and especially a flooding in the Netherlands, is typically characterized by (uncertain) low frequency and very high cost. Large numbers of people inhabiting polders, as well as the relevant property, if affected, would lead to substantial, dependent claims. Covering claims associated with such a disaster requires access to substantial sources of capital.

At the same time, on the part of the public, insurance does not seem appropriate. The point is that thus far, government always used to give aid to the victims of natural disasters based on the solidarity principle, which required a re-interpretation for each particular case (see the Decision and the Law on Compensation of Damage in Case of Disasters and Serious Accidents, both 1998). This means that in fact government practices provide a disincentive for private agents to engage in insurance. Also, those individuals, who expect that the government will at least partially cover private damages incurred in case of flooding, do not see any reason to buy an insurance policy.

Other issues may possibly also play a role in individual decision-making. Kunreuther (1997, pp2-5) draws on the literature on decision-making processes with respect to low probability – high consequence events and discusses the issue of individual protection in the hazard-prone areas. He notes the following reasons for behaviour to avoid taking measures in such cases: ignoring the event (it will not happen to me); budget constraints; myopia (connected to personal risk perception, as well as valuation of costs and benefits); and reliance on state disaster assistance. We may certainly notice that myopia plays a part in the case of flood insurance in the Netherlands. We also refer to Heems and Kothuis (2006), who explain the lack of consciousness in Dutch society concerning flood risks by the following factors apart from the perceived general feeling of safety: lack of experience connected to a flooding event; not considering water as a source of danger; lack of information and facts distributed to the public concerning current risks; and, finally, the collective character of flood protection, which in fact can be seen as leading to the free rider problem when this concerns taking measures. As a result, the current situation in the Netherlands, according to the authors, can be described as a ‘bungee jumper’ effect, when people inhabiting polders consider it safe to live with the permanent danger of flooding behind the dikes, the strength of which they deem reliable. As a starting point to unfold this problem, Heems and Kothuis suggest that proper risk communication takes place.

The above discussion regarding the considerations of insurers and the public in general in the Netherlands suggests that it is of crucial importance that agents on the insurance market have appropriate incentives. An eventual transition to the principle of shared responsibility in the Netherlands and emergence of a market for private insurance will demand a clear determination of roles with a corresponding set of rights and responsibilities for each participant.

The Role of Government

Another issue from the overlap of public-private domains concerns the role of government in steering economic development, which we also briefly mentioned in Chapter 3, Section 3.2.4. All around the world, economies are to a certain extent regulated by the governments. For us it is of interest to consider the specificity of developments in the Dutch situation and the role of government in economic policy-making in the aftermath of a disaster. In the light of the shifts between the private and public domains in the Netherlands concerning flood protection, one of the scenarios that we can assume for future developments is that 'under normal circumstances' the government is willing to delegate part of its responsibility with regard to flood control and water management in the country to the public. At the same time, the government can choose to remain a stabilising factor and a source of 'last resort' in emergency situations and consciously assume the responsibility for steering post-disaster recovery of society. One of the aspects in the efforts for putting the country back on track is the economic side of the calamity.

Looking from an economic perspective, if a part of a country is hit, which hosts important production facilities, that part of the established economic network is lost. That is, the system suddenly loses constituent parts and cannot keep on working as before. A number of producers economy-wide lose their customers, others lose suppliers, and consumers are not able to obtain the desired consumption goods, causing an avalanche effect throughout the economy. In addition, various production sectors may suffer damage to a different extent, which implies asymmetry of effects (as we discussed in Chapter 6 in developing our model). This can create imbalances between the various sectors within the economy, leading to supply and demand shortages on various markets. Imbalances can not always be automatically restored; probably sometimes governments choose to assume responsibility and either temporarily introduce more regulation in the markets experiencing severe problems or provide appropriate incentives to various agents with the aim of facilitating post-disaster recovery. This means that, most probably, economic policy is required to assist the markets in clearing. To be ready for emergency situations, the government thus needs to know its options, and above all needs to have insight in how the economy may respond to various stimuli under the circumstances that go beyond the scope of 'business-as-usual' practices. In the next Section, we shall discuss how economic modelling can be applied.

Furthermore, there is clearly a time horizon issue for proactive policy formation for the risk-averse policymaker. An example of such a policy would be the protection of a particular area, or a deliberate spatial redistribution of activities (in order to make most disaster-prone areas less densely occupied by industry and inhabitants) as a loss avoidance strategy for a potential calamity. In comparison to the 'do-nothing' case (MAFF, 1999), these assets would be protected, and thus the costs of loosing them would be avoided if a flooding breaks out. Evidently, these are examples of long-term policy measures. This brings us to the point that in fact short- and medium-term approaches should be conceptually distinguished from the long-term perspective. When talking about long- and very long-term policy, often Hicksian sustainability concepts enter, in the sense that the choices of future generations should not be compromised for the sake of choices of current generation (see also Brundtland Report, UN, 1987). This implies that we have to think of ways to enhance the robustness and resilience of the systems in question on the long term in preparing for a calamity, or in steering recovery when responding to a disturbance. This implies a different set of concepts and variables in taking today’s decisions than when policy-makers aim at the short-term horizon. Also, when considering the cost-benefit analysis of pre-disaster measures, outcomes of analyses may vary due to different ways of discounting costs and benefits over time. This also involves the inter-temporal preferences of actors involved in the decision-making process.

All this has implications not only for preventive strategies as described above, but also for recovery planning. We can think of ex-post government policies helping the economy and businesses in particular to cope with the extreme situations in future in the event of a flood (or any other major disorder). For example, the government should probably be alert to a situation where, in addition to the country suffering direct and indirect losses (for the discussion of these concepts, consult Chapter 3) incurred by a calamity, long-term losses associated with the crowding out of domestic production by imports can take place. This may be the case if domestic producers as well as consumers outside the affected area temporary switch to foreign products to substitute missing local goods. If this turns into a permanent trend, goods, which before the calamity were produced domestically and now are imported, are in fact lost to foreign countries (which is in line with our definition of damage, see Chapter 3). To avoid this situation, policies directed at the encouraging of uninterrupted production processes in the country may be pursued.

This means that the possibilities to steer the recovery have to be designed in advance. These contingency plans should form an integral part of the high water protection strategy, as in the immediate aftermath of a catastrophe it should be clear for the decision-makers which options there are and which of them should be preferred depending on the prevailing circumstances. One should realise that in such extreme situations action has to be taken straight away, and the consequences of this action will have an impact on the later development stages. Therefore, recovery and reconstruction have to be immediately directed at the trajectory of the ‘most desired outcome’.

In fact, in the course of this Chapter, we effectively took a broader view of disaster management than just analysing the aftermath of the event, with policy alternatives for steering the recovery. We suggest that several decisions concerning preparedness and directed at efforts to create conditions for resilient systems have to be taken; action and reaction in the wake of a disaster are critical both in operational and strategic decisions for the long-run development trajectories. The rising awareness of the increasing dangers in the flood-prone areas in the Netherlands creates a broader platform for public debate than before, and offers the possibility for new ideas and concepts to surface. For the Dutch government it is even more important to realise which consequences a large-scale flood may have, not only for the area, which may be effected, but also for the entire economy.

8.3. SUMMARY AND DISCUSSION

In this Chapter, we discussed recent developments in Dutch water management and policy, signalling a paradigm change in thinking about flood threats. We saw that for centuries both sea and rivers have continuously been a source of danger. The Delta Plan, which came into being after the disastrous 1953 flood, has for decades set the stage for flood protection in the Netherlands. This was based on the concept of very strong primary defences, organized to withstand extreme water levels. For the highly developed and populated central part of the Netherlands, this amounted to a chance of a flood up to once per 10.000 years.

We saw that this permitted a spectacular economic growth in the provinces below sea level, which ultimately made the country a world player on many markets. However, the discrepancy between the infinitesimal dike overtopping probability, and the alarmingly increasing expected losses resulting in a high and ever growing risk of flooding, demand a different type of approach. It means that the country has to prepare itself for future challenges connected to the rising *risk*, in this context finding a balance between expected probability and potential losses, and growth and development agendas.

These recent changes in the view on water management in the Netherlands have led to a change of approach from one based on probability, to one based on risk assessment. Risk, in turn, is the concept including the interaction between the probability of an event to happen (like a major flooding) with the costs that this event may bring about. In other words, risk is the product of probability and the effects of the expected calamity. Adopting a risk management approach in fact requires a framework that takes the economic side of a disaster explicitly into account. At the same time, there is a need for the assessment of the potential economic damage that a flood may cause. If taken on board, this new initiative may in the long run lead to direct implications, in the first place for spatial planning, accompanied by a further chain of reactions throughout various facets of contemporary society.

Current developments in Dutch water management, as depicted in this Chapter, lead to other questions. One of these is whether everyone has the same right for protection from flooding – which is not the case right now. In fact, there is a discrepancy between safety standards as fixed by Dutch law and the actual situation as it has developed. Here, probably, *the country faces the task to re-distribute safety in a reasonable and acceptable way.* This relates to other issues. At the moment the Dutch government bears the responsibility for protection against threats posed by the water, either coming from the sea or from the rivers. In the coming decade this however may evolve into practices that are different from current ones in many respects. For example, if people want to live or work in specific areas, they also may have to bear a part of the involved responsibilities related to flood protection. This, evidently, can take several forms, all of which have to addressed.

A wealth of issues surrounds the spatial dimension. Firstly, many of the issues on today’s agenda are a consequence of how Dutch spatial structure has developed. The country is basically a patchwork of interconnected polders, which each has different characteristics such as population, economic value, and different safety standards. This means that probability calculations should be based on the much more complex concept of systemic risk where a number of dike rings should be seen as an interdependent system. Another issue concerns the present distribution of activities. A major issue is whether or not the Western part of the country can remain as prominent in Dutch society as it is now. Systematic factors do not look favourable: sea level rise, subsiding ground level, increased precipitation and the expectation of more extreme peak river discharges. The Netherlands has to decide how it will develop in the next decades. Should it keep its core economic activities located in the areas directly behind the dikes, or should it adopt a policy of spreading these activities to the higher areas in the Eastern and Southern parts of the country? Further research will be needed for this.

Given the increasing complexity in which modern societies like the Netherlands are operating, it is nearly impossible to solve water management and (large-scale) flooding problems without embedding them in the broader context of economic development as was the case in earlier times. The seamless interaction between various networks offers rich grounds for debate, which we believe will improve our vision on the water and flood protection problems in future. In this Chapter, we attempted to connect flood protection policy evolution in the Netherlands to economic modelling as a possible means to analyse selected issues, in particular paying attention to the 'effect constituent' of the risk concept. In this context, we state that the economic dimension of disaster consequences is an essential part in understanding, explaining and steering contemporary economies in the direction of the desired development trajectories. In the framework of this thesis (Chapter 6), we developed and presented a methodology that gives insight into the concepts of economic vulnerability and resilience, as well as adaptability and mitigation, which are becoming recognised as topical issues in Dutch water and flood management at the moment.

The division of our analysis in three steps in our proposed input-output model allows tracing particular events and their effects at each stage, and modelling their repercussions throughout the entire economic system. Dividing a complex disaster phenomenon into three comprehensive stages, 1) accounting for survived production capacity; 2) convergence to (new) equilibrium and managing recovery; and 3) the analysis of effectiveness of proactive measures, is considered to comply with the needs for flood loss analysis and decision-making support at times when significant shifts in water governance are taking place in the Netherlands. We suggest that scenario analysis provides significant advantages, opening up multiple opportunities for analysis and action. We hope to have shown that this three-stage approach, analysing the economic consequences of large-scale disturbances, has the potential to mature into a fully-fledged tool for supporting decision-making on a national, as well as on international levels.[102]

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[102] We may also notice that international cooperation is gaining prominence in the last decade marking a trend towards paying more attention to flood protection issues. Mitchell (2003, p.568) points out: "In Europe, concern about flooding has grown rapidly in recent years and has resulted in significant public policy responses by transnational organisations as well as national ones." Mitchell distinguishes a number of driving forces behind these developments embedded in a dominant consumer-oriented economy, which in fact contribute to the increased risks of flooding. Among others, he is mentioning such factors as the movement of exporting industry to waterside locations; the phenomenon of North to South industrial migration; shift towards transportation infrastructure, watershed protection and water supply, nature conservation, and recreation as more important floodplain land uses than traditionally dominant agriculture; landscapes and ecosystems that become extensively modified by humans; growing urbanisation, and others. Mitchell notices that these processes are in particular characteristic of Europe, and are even more intensified by the decreasing willingness of European nations to tolerate floods, imposing high flood-protection standards, probably pioneered by the Netherlands which seems to become a 'zero-risk' society (see also Tol *et al.*, 2003, p.579). This all together requires an integrated solution, which is sought to be found in cooperation between the European countries.

Chapter 9

Concluding Remarks and Issues for Future Research

9.1. SUMMARY AND DISCUSSION

In this thesis, we studied the economic aspects of major disasters in the context of developed modern countries. Our research was inspired by earlier empirical research into the consequences of a big flood in the coastal areas of the Netherlands. We observed that the area of disaster studies was very diverse, but also that certain elements seemed to be lacking or underdeveloped. Our study focused on one such area.

We had to refrain from many aspects, such as environmental, ecological, social and political impacts, or human victims. The study focused on two particular aspects of a disaster, its *scale* and the *structure* of the stricken economy. Thereby, we focused solely on *highly developed* economies. The international literature clearly pointed to the need for separate attention for the issues we raise. Various stakeholders need to gain further knowledge of disastrous events and their repercussions throughout modern societies. At the same time, expertise in this area is not really extensive. The analysis of *major* shocks is conceptually different from that of relatively minor shocks. Also alternatives, such as viewing a big disaster as a kind of aggregate of a number of ‘small’ disturbances, were not convincing. Here, the scale of the event, which seriously undermines the ability of a system to operate, plays a leading role. We had to conclude that research of this kind is still relatively new; attempting to gain additional insight into the processes behind disaster events in modern economies has only recently become a separate theme of research. Essentially, this has yet to gain a more definitive shape as a specific field of study.

Current attempts at studying calamity consequences are very diversified, by country, type of (natural) hazard, modelling type or purpose; we discussed these issues in Chapters 2 and 3 of this thesis. This raised another issue, namely that a set of *commonly* accepted concepts used in disaster research and their definitions are still missing. In our study, we decided to start by addressing the core concepts in disaster analysis. We started with the notions of a disaster and a catastrophe - which are identified as severe shocks, generating widespread disturbance in terms of physical damages and loss of connectivity within an economic network. Although catastrophes are seen as ‘major disasters’, within the scope of this thesis we treat them as equal in terms of scale, as opposed to the minor or incremental changes conventionally addressed in economic literature.

As stated, the inspiration for our research was the situation in the Netherlands where the dynamics of the danger of a flood are changing. One of the most important aspects of a disaster is the *disruption* it brings about. Clearly, a *big* disaster will bring about big disruption. It appears that the impact a disaster can have strongly depends on the nature of the country or region. For example, it depends on whether the economy is developed or still developing. Also, it depends to a large extent on whether or not the country has prepared itself for a possible catastrophe. Essentially, these aspects of disaster analysis can be described by notions such as vulnerability, resilience and adaptability (see Chapter 2 for a detailed discussion). These concepts have recently become topics of particular interest and wide debate in scholarly research. We have to stress that these notions (i.e. vulnerability, resilience and adaptability) were 'borrowed' from other social and natural disciplines. This meant that they also had to be given a context-specific interpretation when used in disaster analysis. In this thesis, we have attempted to present a survey of the literature by authors with an economic background, as well as authors from the natural and social sciences. In this manner, we interpret economic *vulnerability* (to hazard) in terms of a measure to incur damage. Economic *resilience* (of a system) is then the ability of the system to cope with a disturbance, adjusting to the new circumstances and conditions and maintaining its vital functions. *Adaptability*, in turn, is seen as the ability of the system to prepare for potential hazards, thereby aiming at decreasing its vulnerability and improving its resilience capacity. In connection with *sustainability* notions (broadly interpreted), adaptability and resilience-theory applications could yield their best potential – thereby obtaining a certain normative content.

Consequently, because of the disruptions incurred, the affected economy faces *costs*. Here we should not think of costs in terms of a single number. Disasters, imposing serious disturbances into business-as-usual practices, everyday routines and established relationships, are too complex to reduce their impact to a single figure. Clearly, many types of costs are involved, such as loss of human lives and productive capacity, objects of cultural and historical value, environmental contamination, psychological trauma, and so on. In this study, we focused on the economic costs in terms of lost – in fact, unrealised – production capacity.

The measurement of costs is a major issue. Costs incurred as a result of a calamity can be broadly sub-divided into 'direct' and 'indirect' costs. However, there are differences in opinion among researchers concerning the definition and interpretation of these terms (we concentrated on these issues in Chapters 3 and 4 of this thesis). In this study we considered losses resulting from a direct 'contact' between the hazard and the assets as 'direct', including loss of associated business flow. On the other hand, losses resulting 'elsewhere' as a consequence of loss of connectivity within an economic system, are referred to as 'indirect'. We also pointed out that the typology itself of the costs connected to a calamity requires special attention.

First of all, there is the difference between *measurement* and *inference*. What we mean is that the estimation of direct costs, such as hazard-induced damages, requires a different approach than the estimation of indirect cost. In particular, physical damage has a specific spatial dimension and known scope, which facilitates measurement. At the same time, direct and indirect losses, connected to the interruptions of circular flow, are much more difficult to trace and are not only a matter of measurement, but rather of inference. Furthermore, indirect costs often reveal themselves far beyond the affected region, and can in fact become visible hundreds of kilometres away from the hazard-affected area. This meant that in order to gain insight into the nature of such losses within a larger entity (like a whole country) we need a suitable modelling tool that is capable of capturing the interrelationships (or a sudden lack of them) within an entire system.

Secondly, we pointed out the importance of introducing a spatial element in the analysis. Disasters have a definite geographic dimension, so location enters into the equation. As mentioned in the above, indirect losses can manifest themselves over large distances and even in other countries. That is, the spatial extent – and how we define it - of cost estimation will affect the final outcome.

Thirdly, the temporal dimension is important. Here, we can distinguish between immediate or very short-term effects, medium-term, and long-term impacts. Immediately after a calamity, only direct damage is visible; one only starts to realise somewhat later that there are also disturbed economic relationships and links. If damage assessment is restricted to this stage, only a limited amount of costs can be identified. In the short-term and the middle term, distracted linkages in an economy gain effect, and economy-wide indirect effects become apparent. Non-produced goods, absent suppliers and customers, closed factories and shops, broken roads and communications are the signs of indirect impacts, in the affected area, and outside it. Before all actors find their place in the new situation and the system comes to a new balance, many costs categories will be observed. Taking the recovery stage into account will provide another estimate of total disaster costs. In the longer-term perspective, we can look at the disastrous event as pushing a region or an entire country away from its long-term development path. We define the total costs of a calamity as the difference between the potential that the economy could have realised without the disaster, and the actual development up to the point where the post-disaster track meets the potential one. Here, the time horizon depends on the ability of an economy to return to normalcy. Some economies can catch up with their original path within a couple of years; for others it can take a decade or more. If a disaster has been a severe one, and a system is not able to return to its development track at all, this theoretically raises the costs of a catastrophe to infinity.

Our fourth observation with regard to cost assessment concerns the choice of framework. Depending on the selected objective, a number of perspectives to costs can be considered. In the context of an economic disaster, theoretical financial and economic cost perspectives are available. Here it is important, in order to avoid confusion, and to apply the concepts consistently according to the chosen perspective.

Finally, the distinction between stock and flow measures of losses should be made. Again, depending on the type of loss, stock or flow concepts can be applied; for example, it is more appropriate to measure property damages as a loss of stock, while it is more appropriate to measure business interruption in terms of losses of flows. To keep the appraisal consistent, as pointed out in the literature, it is essential to measure each loss category either in terms of lost stock, or in terms of lost flow, but not both. In Chapter 5, we pointed out that the Leontief model, in particular in its dynamic versions, offers interesting possibilities for an integrated view on this.

The discussion, involving stock and flow measures, brings us to another point. If existing relations within an economic network become disturbed or destroyed, the capacity to generate a surplus is also affected. Here we focus on the disruption of relations within an economy and its effect on the surplus producing capacity. To describe the interrelations (and also the loss of them) within an economic system, we employed the notion of a *circular flow*. The notion of *circularity* is based on the idea that a commodity within an economy can appear simultaneously as an input in one activity and as an output of another. This provides interdependence between producers and consumers. This way, we can visualize an economy as an interconnected system of multiple buyers and suppliers operating on various markets. To also formally express this interdependence between the various groups and categories of agents in the economy, we decided to adopt the framework that multi-sector models provide. The term 'sector' has a broad meaning in this context. It can mean groups such of producers or consumers, but also stand for separate industries such as various types of agriculture, heavy or light industries, services, *et cetera*. In particular, we looked at the capacity of a country to generate a surplus or net product. If we picture the pre-disaster situation in terms of circular flow, the situation is *balanced* in the sense that buyers and sellers coordinated their respective decisions. If this circular flow is disturbed, *imbalances* and *disproportions* arise. Consequently, we chose to study the impact of a disaster through the notion of imbalances caused by disruptions in the interconnected network, which form the economy. Major disturbances, as we portray them, break up connecting lines between sellers and buyers, and also between factory or work place and the individual worker; the establishment can be gone, or the worker can have been incapacitated, resulting in a loss of employment.

Having adopted a multi-sector model, the question arises: which one? Today's models are to a large extent based on the idea of 'balances', not 'imbalances'. Actually, during the literature review and conference discussions, we gradually realized that we had to return to basic philosophies underlying multi-sector research to be able to apply them to 'disequilibrium' modelling. That is, we had to go back to the 1920s and 1930s, to authors like Walras, Cassel, Wald, Von Neumann and the early work of Leontief. We referred to Schlesinger (see Chacko, 1976), who pointed out that economic theory should not only explain nonnegative prices and the quantities produced from scarce resources, but also *which* goods are scarce and which are 'not scarce' or 'free'. Also, a theory should be able to explain which of the existing productive activities are not used at all. To be able to address these types of questions, we had to go back to the views of John Von Neumann.

Von Neumann addressed a very particular question about economic growth. He showed that economies, which are able to support a circular flow, possess a so-called proportional or balanced growth, a situation where all sectors grow at the same rate. This unique growth path obtained a special normative status much later, in work concerning optimal growth after World War II. This approach also provided information on goods which are actually consumed as inputs and produced as outputs, and in which quantities. It also provided information on the *overproduced* (i.e. 'free') goods, *and* the activities and technologies that are used or not used. Later work by others produced special algorithms to actually calculate this growth rate, the accompanying financial parameters, and the corresponding outputs and prices. Von Neumann's model was 'closed' in the sense that no outside resources were required to maintain the circular flow. This meant adopting a perhaps somewhat forced concept of activity-producing labour while absorbing consumption goods in fixed proportions. In addition, disposing of oversupplied commodities was no problem. Leontief, only a few years later, published a *Tableau Economique* of the United States. This Tableau also was closed for consumption, without, however, considering labour as an activity like all the others. Only later, the so-called open input-output model became available for impact analysis in the form of multiplier analysis. However, the Leontief models are somewhat less flexible in addressing issues of relative abundance and shortage. This is the reason the Von Neumann formulation was adopted as providing the basic outlook. For us, it was important that we now could say more straightforwardly what is overproduced and what is unused as a consequence of the emerging imbalances in the disaster aftermath.

Essentially, the question a disaster-researcher faces is how to model a post-disaster economy. In fact, one can formulate the problem as follows: Where are we? And where do we want to go from here? Also: How can interrupted activities be restored? Where should the means for assistance be directed to in the first difficult moments? Clearly, in such situations, we have an extreme scarcity of resources at certain points; decisions on resource allocations are critical and have to be based on factual information. In other words, in order to make 'optimal' decisions, we initially have to know what is available and what is not. Furthermore, we should also have an idea about in which direction we want to go. So, there are two things we want to know: firstly, what is the state of affairs immediately after the event? What is damaged, lost, or destroyed? What is left untouched and remains functioning? What can be used, and what appears to be of no use locally, regionally, or nationally? And secondly, what is the strategy to be followed for recovery? This means that before we get to reconstruction and recovery modelling, we need some sort of accounting for those assets and resources that survived the disaster and remained intact. Getting to know where we stand, immediately after an outbreak, and how far we are from what can be called 'business-as usual', requires a study of its own. It was a revelation to realise that existing literature does not cover this step as part of disaster model building. Yet, we consider this 'accounting' stage a highly important element in thinking about major calamities and their consequences in modern complex economies, where the scale of the disturbance is a determinate factor. So, firstly, we decided to focus on the immediate after-catastrophe situation where part of an economy is destroyed, thereby sometimes introducing heroic assumptions regarding the surviving elements.

Naturally, there are many different opinions on how an economy can develop after a major shock. What should we aim at? A proper goal might be restoration of the pre-catastrophe situation. We can assume that, before the calamity, markets were in equilibrium, where consumers were buying goods and services based on their preferences, maximising their utilities, and producers were producing the necessary amounts of those goods and services based on profit maximisation principles and applying the 'best' technology. Because that equilibrium was not just coincidence, but rather the result of consumer- and producer-optimising behaviour, this would indeed be a proper goal for where the economy should be (again) after the recovery stage. Alternatively, it can also be seen as providing a convenient threshold scenario to compare with other recovery paths.

Modern economies are characterized by many types of *rigidities*. These can be of a technological nature, as stressed by Von Neumann and Leontief. However, they also can be of an institutional, cultural or behavioural nature. In our work, we focused on such rigidities in the form of engrained views on the composition of the final consumption basket, and on the role of full employment. That is, after the disaster, consumption and employment issues basically dominate the agenda. We modelled this in terms of a policy to restore 'some' kind of economic circular flow where labour's real wage (i.e. its consumption bundle) is paid for by labour's input into the productive sectors. In our basic model design, described in Chapter 6, Sections 6.3 to 6.5, we derive what is called the Basic equation under the assumption that labour losses are proportional to the losses of sectoral capacities after a disaster. As a result, we arrived at the description of the post-disaster surviving production capacity, with maintained proportions between the sectoral intermediate and primary inputs, but with distorted proportions (i.e. relative to the proportions observed in the pre-catastrophe circular flow) between the sectors and intermediate and final consumption demand. This clearly is a first approximation, because in reality labour often is more ‘flexible’, which provides opportunities for fine-tuning at the sectoral level. We addressed this possibility in Section 6.6 of Chapter 6. There, we derived an alternative Basic post-disaster equation based on the assumption of *dis*proportional losses between the labour force and sectoral production capacities. In this instance, we also arrive at the different post-disaster capacity description. *Focusing on the all-important role of the consumption-jobs relation, in this way we arrived at what basically is an ‘upside-down’ input-output system: in cases of a relative abundance of labour, the intermediate input part, i.e. the technological infrastructure, now essentially becomes the scarce resource!*

In modelling recovery, we focused on a strategy directed at a speedy growth after a calamity, which would in the medium and long run ensure the creation of new work places. Furthermore, expanded production to satisfy final demand will generate more labour income, which in turn will ensure the stability and self-sufficiency of the system in longer term perspective. We thus assumed a policy decision to return to the pre-calamity proportions. Starting from the basic post-disaster equation, we are then able to identify, with the help of Von Neumann theory, which sectors are the ‘bottlenecks’ for the recovery. Essentially, this means that because some of the sectors are struck badly, they act as a limiting factor for the entire economy. This means that other sectors, with a greater post-disaster productive capacity, in any case in the short run will produce goods in abundance relative to what is necessary both for intermediate and final consumption, thereby becoming largely superfluous.

9.2. DISCUSSION OF MODEL IMPLICATIONS

We attempted to develop an integrated approach that is transparent, methodologically correct, and empirically applicable for serving as a reliable tool for policy analysis and advice. We also provided a connection to a more integrative water management approach in the Netherlands. In Chapter 8 of this thesis we discussed which tools our model can offer for the analysis of flood threats in the Netherlands as well as for decision-making and action in a broader international context. Our adapted input-output framework, introduced in Chapter 6, can be used for exploring scenarios for adaptive policy regarding the threat of flooding.

In Chapter 8 we put sharply that in the Netherlands, where economic and flood protection networks are overlapping, water management policies cannot be considered separately from the long-term development of the country as a whole. The analysis that we presented can ultimately result in proposals concerning adjustments in the current political economy of the country as a whole. It may be necessary to prepare a set of well-based and thoroughly studied options to guarantee long-run sustainability under conditions of increasing risk of climate change, particularly in its interaction with dense socio-economic, administrative and political network-based interests. Besides, it may be that changes introduced in present policies (with a certain legacy of ‘technocratic’, path dependent polices), only mark the beginning of bigger shifts such as those addressed in Chapter 8. Thus, water management and flood protection policies cannot be viewed separately from the national long-term development path. Essentially, this asks for the co-evolvement of modern economic thinking and current policy-making.

We suggest that the proposed economic model can serve as a tool that lends itself to a three-fold set of targets in current water and flood management in the Netherlands: a) establishment of an integrated way of thinking about large-scale catastrophes; b) improvement of the economic methodology for disaster analysis; and c) introduction of new thinking about policy implications of disaster analysis.

The first step to this three-fold approach is to get a proper perspective on the nature of the post-catastrophe disruptions. To this end, it is necessary to go back first to the pre-disaster equilibrium notions as modelled by circular flow based schemes. Against this background, we reviewed the interconnections within and between the various sectors of the economy, disturbed as they are by the hazard. This resulted in the so-called Basic equation, which is derived based on adapted input-output accounting (see equation [6.18], and equations [6.35] and [6.39] in Chapter 6). Using the equations for labour and total output, we were able to establish in a systematic manner which part of intermediate as well as final demand 'drops out' of the circular flow system as a result of the calamity. The Basic equation, in fact, provides a reflection on the situation in the entire economy in the form of a systematic 'inventarisation' of the remaining production capacity. However, it is not yet a representation of an operable economic system because it only reflects disrupted internal proportions.

The second stage consists of addressing post-disaster imbalances. During this stage, the Basic equation becomes our point of departure for an investigation of the options open to an economy when entering the post-disaster recovery. Many policy tracks are open, and in Chapter 6 we illustrated one of them, i.e. a return to the pre-disaster proportions.

During the third stage, a special type of cost-benefit analysis can be employed, based on the geographic dimension of the catastrophe. As a result, our model enables us to estimate the macro-economic effects of particular *ex ante* preventive measures on production facilities or residential areas lost or saved per formulated scenario. Knowing the spatial distribution of economic activities, we can assume that if the country, or parts thereof, were better protected, the consequences of a calamity at the national level would be less massive. This provides us with a possibility to analyse multiple pre-disaster conditions, policy measures and recovery paths, and to contrast these with the total expected costs of a catastrophe. Thus, comparing the outcomes to the related costs, preferred scenarios can be singled out.

9.3. KEY CONTRIBUTIONS

Let us briefly recapitulate our research goal and questions. Above all, we hope that the answers provided to the research questions, formulated in Chapter 1, added to our knowledge in the field of disasters studies. Our goal was to develop an integrated approach for the economic analysis of disasters in modern, highly developed economies. The reviewed literature has shown that systematic thinking, incorporating important elements of analysis, such as disaster preparedness, reflection of imbalances and recovery thereafter, has not yet fully developed, while detecting a need for such a tool in policy-making.

We can conclude that *five specific contributions* of this thesis can be recognised. Firstly, we have introduced the conceptualisation of the notions of a ‘disaster’ and a ‘catastrophe’, as well as the notions essential in disaster analysis, such as ‘economic vulnerability’ and ‘resilience’, and other related notions. These are found in Chapters 2 and 3. Secondly, we have illuminated the potential of the input-output types of model, applied to the studies of structural breaks (Chapters 4 and 5). Thirdly, we have proposed a novel methodological advancement in the development of an adjusted input-output based model. This can become a flexible instrument for the structured analysis of the processes inside an economic system, focusing on policy as well as on action, in which three phases can be distinguished: 1) the immediate disaster consequences (vulnerability); 2) the economic reconstruction and recovery in the disaster aftermath (resilience); and 3) policy instruments and measures for advance preparation to a potential hazard (mitigation and adaptation), as found in Chapter 6. Fourthly, we provided an improved theoretical foundation for the adjusted input-output disaster model. This now has ample potential for further development (such as exploring the opportunities for linking with other approaches like CGE), and empirical application (fitting it to more practical needs and exploiting various sources of data). Last, but not least, we offered the exploration of the Dutch case of water and flood management, which provided the established methodological framework in the context of emerging risk approaches. This is discussed in Chapters 7 and 8.

In conclusion, we would like to stress once again that the approach to *major* disaster modelling offered in this thesis has been proposed as one of the possibilities to look at the processes behind a major calamity in modern societies. Clearly, we do not exclude that other modelling practices will be developed in this field. Nevertheless, we would like to emphasise that in developing this approach, we started from basic questions, initiating a study into the fundamental issues guiding disaster-modelling philosophy. Starting from the idea of circularity and circular flow within an economic system, we arrived at a comprehensive input-output logic for describing disastrous events in complex economic systems. We suggest that, having developed this approach, we built a solid foundation for further elaboration and construction of more complicated modelling tools to gain further insight into the complex interrelations of severe disturbances in contemporary economies.

9.4. LIMITATIONS AND TOPICS FOR FUTURE RESEARCH

There are a number of issues that are likely to be included in the future research agenda of disaster events in modern economies. First of all, we addressed the importance of further integration between the many themes that must be addressed in disaster analysis. This also requires increased cooperation between the disciplines or sub-disciplines guarding the building blocks thereof. Arriving at an integrative approach would clearly require a further focus on inter- and sub-disciplinary work.

Also, as we have seen, disasters have a definite geographic dimension. Therefore, location gets involved in a fundamental way. Here undoubtedly many new applications are awaiting us. There is also the temporal dimension. We pointed out that these aspects require additional sets of definitions and concepts. In our study, we also put forward that it is most important that there are at least some insights into the type of post-disaster economy to be aimed at. Here we encounter an entirely new set of questions facing the economic modeller. In model terms, this requires attention for different types of multipliers, including, in fact, the whole gamut of semi-legal to completely illegal activities one often finds in the wake of a disaster – not addressed in this study. Mathematical programming techniques can also become important, whereby many accepted truths, such as the famous non-substitution theorem (Samuelson, 1951), may have to be re-invented.

As we have seen, the input-output *table* plays a dominant role in our type of research. However, in future research, we may run into complex issues of adjustments of the table. For example, we may be forced to transfer parts of the disaster-related expenditures from the final demand column or columns to the appropriate column in the transactions table. This will directly influence our insights into the technological input requirements. It will also influence the estimations of the value-added part because what used to be accounted for as consumption now becomes part of intermediate demand, including the complicating presence of tax-subsidy and other price-affecting rules and regulations.

Finally, it may be worthwhile to reflect on some specific connections with other economic sub-fields. International competitiveness and attractiveness of a country for businesses are, according to the insights of the New Economic Geography (NEG), heavily influenced by a specific set of factors. Nowadays the thought of filling the gap of 'spacelessness' of much of modern neoclassical economic theory is gaining impetus (see, for example Fujita and Thisse, 2002; as well as Stelder, 2005; Capello, 2007). We can apply NEG insights to see how spatial economic activity may be reshuffled after a major disturbance - like a vast flooding in the Netherlands. NEG proposes a distinction between regions characterised as 'centre' and 'periphery'. This view is inspired by spatial effects, imperfect competition on the markets in different spatially distributed areas, and the transportation costs. At some point, the 'centre' becomes the area where concentration effects, which affect production as well as consumption, will take place. At that moment, increasing returns to scale production effects take over, thereby creating an amalgam of centripetal and centrifugal forces that attract more and more businesses and labour to the area. Depending on the scale of analysis, central and peripheral regions can be distinguished within a country (like the industrialised West in the Netherlands versus the East and the North), but also within a larger unit, like Europe, where the 'Blue Banana' often is taken to represent the agglomerated 'centre' (see Hospers and Steenge, 2002; Hospers, 2003).

In this light, our analysis can be given another twist. NEG actually offers an explanation of accumulation and agglomeration effects, though it does not explain why 'centres' are found at the locations where they developed. We can now suggest additional mechanisms for steering the way certain possibilities emerge for regions to gain the central position and how they can be realised. In this context, we have to consider if, after a disaster hits such a 'central' region, it will recover and maintain its position, or if the conditions will favour some now peripheral regions to gain more importance; will other agglomerations take over from the flooded 'centre'? These are crucial questions to be answered.

At the same time, a look at the map of Europe suggests that the Netherlands is a relatively small country, and the close proximity of the Ruhr-Rhine agglomeration can make a difference in this type of logic. Economic actors (businesses and possibly consumers), instead of moving their activities within the Netherlands, thereby in the end forming new 'centres', can also seriously consider the advantages of shifting their attention and locations to alternative 'saddle points'. Neighbouring Germany, France, Belgium and the UK are countries offering existing 'clustering' possibilities.

Links to modern Political Economy can also be considered. A significant change in policy will incur costs. Often these are fixed costs, associated with investments necessary for a change to take place, and produced in the short run, i.e. directly before and at the start of the change. These costs are not necessarily always expressed in monetary terms. One can think, for example, of efforts and means invested in basic research into the issue, bringing the issue to the top of the political agenda, as well as costs connected to implementation of the new policy or project. At least a part of these costs will become sunk costs, which are project-related and irrevocable. However, the benefits of the new approach are often monitored as a discounted flow of future benefits, usually in terms of lower operational costs. This means, that there is then a temporal gap between incurring the costs and reaping the benefits. This discrepancy can make politicians, who are elected for the office for a limited period of time, averse of taking decisions on significant changes in policy, because that would only increase costs, without benefits in the short run. Such a stalemate situation can lead to rigidity of policy, or, as it is sometimes referred to, 'path dependence'. This is argued *inter alia* in Pierson (2000, 2004), Woerdman (2004) and others.[103] We can apply this argument here with regard to the pre-disaster preventive policies. It usually takes time and possibly a real disaster for the policy-makers to 'invent' a new approach to protection. In this sense, the situation in the Netherlands with respect to high water protection policy appears to reveal similar 'path dependent' characteristics.

We saw in Chapter 8 that established current practices in flood protection policy in the Netherlands, namely the construction of a highly complex system of dykes, led to the emergence of very intense and steady perceptions in society on flood protection. Practiced for decades, this way of dealing with water has seemingly become customary, and by definition not subject to change. Further investigation into the matter probably would identify a certain rigidity of the dominating policy, i.e. a serious case of path dependency. Being 'locked in' for decades, new, more integrative approaches in thinking about floods are only slowly emerging (as discussed in Section 8.3 of Chapter 8), and will need much time to mature into a real shift in action. A study of Van der Brugge, Rotmans and Loorbach (2004) points to a changing water management regime towards a more participatory style. Still the government has to supervise the emergence of conditions that will guarantee long run sustainability under circumstances of increasing climate pressures and expected socio-economic developments in the Netherlands. Gaining further insights into the political economy of decision-making applied to the case of Dutch water and flood management can also be a fruitful ground for further investigation.

INSTEAD OF AN EPILOGUE

In the context of hazard management, we also come across the concept of the 'risk society' emerging in the era of post-modernity, as introduced by Beck (1992) and Giddens (1990, 1999). We have briefly touched upon it in Chapter 1. We may see several shared elements between the principles underlying our approach, and the ones guiding the existence of the risk society, although the latter concentrate on the risks

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[103] Although path dependency of political processes and policy formation is commonly explained by the existence of increasing returns in the political processes, it can be also argued that the rigidity is triggered by the so-called 'sunk cost fallacy'.

generated by and within post-modern societies, abstracting in a sense from pre-industrial hazards. In fact, one of the basic sources of increasing risk in modern societies nowadays is the ongoing accumulation of wealth, which inevitably becomes subject to various hazards. In our discussion of the Dutch situation in the highly developed and densely populated polders, we have also pointed to this phenomenon. In fact, natural hazards, when intertwined with human-induced systems with better welfare positions, also obtain higher devastating potential. In this sense, we must agree that any disaster is a result of the techno-economic development itself, as asserted by Beck (*idem*). Furthermore, risks in modern societies have acquired a new quality when repercussions occurring in the aftermath of a calamity are no longer tied to their place of origin. Namely, increasing complexity (and specialisation) triggers what Beck (1992, p.22) refers to as “the unknown and unintended consequences”, which seem to be akin in nature to the indirect effects that we are discussing. In fact, those effects that go beyond the directly damaged assets and property, as pointed out in Chapter 3, are subject to such interpretation in addition to ‘simple measurement’. Besides, in the theory of risk society, because of interconnectedness within modern systems, perceptions of personal risks seem to change, while the danger of group risk or even risks with global consequences is growing in potential. To this end, we suggest that an analysis of major calamities should be carried out in the context of an integrated approach, and the consequences of these should not be seen as a single discipline phenomenon, but as a complex event tied to a manifold of contexts and possessing a multiplicity of facets. This also means that an inquiry into such incidents requires an ability to have a broad overview of processes guarding the disaster, and thus asks for an appropriate scale of analysis. Finally, the content of risk concept in the risk society is directly connected to action, or, rather, pro-action. This is a consequence of the time component of risk and the anticipation of future threats, by means of which ‘not-yet-risk’ events become real today (which we touched upon in the light of the time span for decision-making in Chapter 8). This implies, in turn, that risk societies can be characterised by an explicit orientation towards prevention. In this sense, we need to anticipate the unexpected today (as put forward by Jones, 1997), and take action to prevent catastrophic consequences. Here, the future, and not the past, has the power to determine the present.

Nederlandse Samenvatting

Deze dissertatie behandelt het thema van een grote ramp in een hoog ontwikkeld land. We kunnen daarbij denken aan een grote overstromingsramp in het Nederland van het begin van de eenentwintigste eeuw, maar ook aan een aardbevingsramp in Japan of in het Amerikaanse Californië. De vraag wanneer een ramp (of catastrofe, we zullen beide termen afwisselend gebruiken) 'groot' is, is een subjectieve, wij zullen slechts een aanduiding geven. Essentieel is dat de catastrofe het functioneren, direct of indirect, van aanzienlijke delen van de samenleving onmogelijk maakt, en het voor langere tijd zeer moeilijk maakt om op dezelfde, of vergelijkbare, voet voort te gaan. De nadruk in dit proefschrift ligt op de *economische aspecten* van een dergelijke ramp. Dergelijk onderzoek is veelal ingegeven door de wens om een goede methodiek te hebben om de schade te bepalen. Indien beschikbaar kan deze op haar beurt weer dienen als een vertrekpunt voor allerlei preventieve maatregelen (hoofdstuk 1).

In hoofdstuk 2 worden de kernconcepten van het huidige catastrofenonderzoek besproken. We gaan in op de verschillende definities van een ramp, en komen tot een eigen definitie. Ook gaan we in op het 'schaaleffect', d.w.z. de rol die de omvang van de ramp speelt in verhouding tot aard en omvang van het getroffen gebied. De begrippen weerstandsvermogen (resilience) en aanpassingsvermogen (adaptability) komen ter sprake als aspecten van de economische veerkracht (coping capacity), evenals verschillende kwetsbaarheidbegrippen (vulnerability). Deze begrippen spelen alle een rol bij het omgaan met de dreiging van grote rampen in de context van wat volgens sommige onderzoekers een risicomaatschappij (risk society) is geworden. (Naar dit begrip wordt ook gerefereerd in het laatste hoofdstuk).

In hoofdstuk 3 gaan we in op de gevolgen van catastrofes. Het onderzoek hiernaar vond zijn feitelijke start in empirisch onderzoek naar de gevolgen van een grote overstroming in het westelijk deel van ons land. Het ging daarbij om een verondersteld dijkdoorbraak bij Rotterdam die grote delen van de provincie Zuid-Holland onder water zette. Aan ons was de taak om een calculatie uit te voeren naar de economische gevolgen van een dergelijke catastrofe. Bij de opzet werden wij allereerst geconfronteerd met de vraag wát wij precies wilden uitrekenen. Een grote ramp heeft vele aspecten, die allemaal bijzondere aandacht kunnen eisen. Al vrij spoedig echter bleek dat er op het heel specifieke terrein waarop wij ons begeven hadden (een ramp van een dergelijk kaliber), nauwelijks literatuur beschikbaar was. Dat wil zeggen, er was vrijwel geen literatuur naar de gevolgen van een grote tot zeer grote ramp in een moderne, geïndustrialiseerde, en sterk verstedelijkte omgeving.

Niettemin, redelijk veel onderzoek is al beschikbaar naar de gevolgen van catastrofes, zij het op kleinere schaal. Bij een vooronderzoek bleek echter al vrij snel dat er geen eenduidigheid bestaat over wat precies zou moeten worden verstaan onder termen als schade en kosten, en, bijgevolg, de gevolgen van een ramp. De huidige situatie wordt gekenmerkt door een grote mate van verschillen van inzicht. Dit uit zich in een veelheid aan begrippen, concepten en terminologie. Verder is er een veelheid aan invalshoeken voor calculaties rond ontstane schade, inclusief de verzekeringsproblematiek. Gaandeweg gaf dit vorm aan een van de grootste uitdagingen van ons onderzoek, n.l. om een samenhangend beeld te verkrijgen, in ons geval van een ‘grote’ overstroming.

Hoofdstuk 3 behandelt ook een aantal punten betreffende de afbakening van de ramp in ruimte en tijd. Bij het bepalen van de gevolgen van een ramp is het van groot belang om een duidelijke begrenzing te hebben. Ook hier weer blijkt dat te maken keuzes veelal subjectief van aard zijn. Er zijn in ieder geval verschillende stadia te onderscheiden. Allereerst is daar de directe, post-catastrofe periode. Deze is veelal gekenmerkt door vaak onoverzichtelijke en ongestructureerde informatieverzorging, en het eerste opgang komen van noodhulp en opruimingswerkzaamheden. Na enige tijd zullen de meeste slachtoffers geborgen zijn, en bepaalde transport- en informatiekanalen deels weer beschikbaar zijn. Dat betekent echter nog lang niet dat de onderbroken economische bedrijvigheid ook weer op gang kan komen.

Een kernonderscheid hier is dat tussen directe en indirecte schade. Onmiddellijk na een catastrofe is het duidelijk dat er zeer veel *directe*, ‘fysieke’ schade is. Woongebieden zijn getroffen en huizen zijn beschadigd of onbewoonbaar geworden. Hetzelfde geldt voor bedrijfsgebouwen of soms hele bedrijfsterreinen. Ook hier is veel zichtbare, directe schade. Bovenal is er het verlies aan menselijk leven, en er kunnen veel gewonden of zieken zijn. Verder is er het verlies aan dierlijk leven, al dan niet deel uitmakend van menselijke productieactiviteiten zoals agrarische bedrijven. Hiernaast is er de *indirecte* schade. Indien een bepaalde fabriek verloren is gegaan, betekent dat in ieder geval twee dingen: 1) een bedrijf dat leverde aan deze fabriek heeft zijn afnemer verloren, en 2) een bedrijf dat de producten van de betrokken fabriek afnam, wordt niet toegeleverd. Dit zijn voorbeelden van indirecte schade. De schade is echter groter omdat de gedupeerde toeleverancier en afnemer op hun beurt weer hun afspraken en contracten binnen het economische netwerk niet of slechts deels kunnen nakomen. Er ontstaat dus een golfbeweging door de economie die zijn invloed op alle sectoren kan hebben. Deze indirecte effecten kunnen een orde van grootte hebben die minstens vergelijkbaar is met de directe effecten. Er is wel één groot verschil: om de indirecte effecten te kunnen bepalen, is een *model* nodig. En dat vereist een visie op het functioneren van een economie.

In deze studie willen we dus inzicht krijgen in de indirecte gevolgen van een grote ramp, en daarmee ook een interpretatiekader voor de directe gevolgen. Dit betekent dat we de beschikking moeten hebben over een model dat de voor ons doel belangrijke eigenschappen van een economie ordent en interpreteert. In deze dissertatie zullen we de getroffen economie interpreteren in termen van een *netwerk* bestaande uit producenten en consumenten, verbonden in een veelheid aan betrekkingen. Het netwerk bezit daarbij een bepaalde kern die regionaal of nationaal bepaald kan zijn, en die ingebed is in weer grotere, internationale netwerken.

Het probleem is dat we eigenlijk niet geïnteresseerd zijn in het economische netwerk zelf, maar in de onderbreking, of het falen, ervan. Door de ramp kunnen delen van het netwerk niet meer, of nog slechts ten dele, functioneren. Ons doel is nu het interpreteren van de schade veroorzaakt door de ramp, en de daarmee verbonden kosten, in termen van schade aan het netwerk. Dat wil zeggen, we zullen trachten aard en omvang van de schade uit te drukken in termen van de eigenschappen van het netwerk. We zullen hierbij weer gebruik maken van het onderscheid tussen directe en indirecte gevolgen. De directe gevolgen bestaan uit het ‘fysieke’ deel van de schade, zoals beschadigde of verloren gegane bebouwing en infrastructuur. De indirecte gevolgen betreffen dan de uitwerking hiervan op de rest van het netwerk zoals productieverlies ‘elders’, *et cetera*. We zullen nu eerst kort ingaan op de achtergrond van het te modelleren netwerk, en daarna op de gemaakte modelkeuze.

Hoofdstuk 4 plaatst ons werk in de context van modellen en modelexercities zoals die momenteel circuleren. We gaan in op studies die als de ‘Nederlandse School’ gezien kunnen worden. Er blijkt een veelheid aan studies te zijn, variërend over de gehele breedte van micro- naar macro-economisch georiënteerd onderzoek. Deels hebben deze ook betrekking op een andere omgang met de waterproblematiek, zoals in de recente besluitvorming rond ‘ruimte voor water’ (zie ook hoofdstuk 8). We bespreken ook werk uit de internationale literatuur waarin de problematiek van de modelkeuze ook naar voren komt. Tevens gaan we in op vraagstukken rond de afbakening van taken voor de overheid en voor de markt, mede in het licht van de modelkeuze. Inzichten rond de flexibiliteit van een economie blijken hierbij een significante rol te spelen.

Economische modellen (waaronder alle door ons te hanteren modellen) hebben vaak een ingebouwd *evenwichtsbegrip*. Voor de economie als geheel vindt dit veelal zijn representatie in het concept van de *economische kringloop* als basisstructuur voor het hierboven aangeduide netwerkidee. De kringloop behoort tot de oudste en meest fundamentele concepten van de economische wetenschap. Het betreft hier het inzicht dat productie en consumptie samenhangen via markten voor productiefactoren (zoals arbeid), intermediaire en eindproducten, waarbij de productie van een bepaalde eenheid, hetzij het individuele bedrijf of een hele sector, de input produceert voor andere eenheden, hetzij direct, hetzij indirect. Het kringloopidee geldt ook voor ‘de consument’, die in ruil voor eindproducten zijn diensten aanbiedt.

Een economisch netwerk kan op vele wijzen worden vormgegeven en gemodelleerd. Wij hebben gekozen voor een visie gebaseerd op de onderlinge betrekkingen tussen producenten (het ‘bedrijfsleven’), en consumenten (de zogeheten finale gebruikers) waarbij gezinshuishoudingen in de regel de grootste fractie vormen. (De term ‘finaal’ betekent hier dat de betreffende leveringen niet weer een input zijn in productieprocessen van de beschouwde economie). Op hun beurt leveren de gezinnen echter wel weer de noodzakelijke arbeid voor de bedrijven, waarmee een gesloten kringloop ontstaat. We zullen de productiekant van de economie nu beschouwen in termen van *industrieën* of *sectoren*, d.w.z. bedrijven geaggregeerd rond gemeenschappelijke kenmerken zoals soortgelijke producten of vergelijkbare productieprocessen. Ons analyseniveau is daarbij het meso-niveau van bedrijfstakken, waarbij opgemerkt moet worden dat de definitie van een bedrijfstak zeer flexibel bepaald kan worden, afhankelijk van het precieze doel van de studie. Deze optiek betekent wel dat we afgezien hebben van enerzijds een micro-economische optiek, waarbij de individuele producenten of consumenten centraal staan, en van anderzijds een geaggregeerde, macro-economische optiek. De reden hiervoor is dat een keuze voor het meso-niveau veel directer de relaties legt met het centraal staande concept van een economisch netwerk. (Niettemin, onze uiteindelijk gekozen methode is flexibel genoeg om zeer gedetailleerde geografisch georiënteerde (GIS) data te kunnen incorporeren, zie de hoofdstukken 5 en 7).

Het meso-niveau wordt vaak geassocieerd met de familie van multisectorale modellen. Wij hebben dit overgenomen, waarbij de term ‘multisectoraal’ ruim wordt geïnterpreteerd, d.w.z. zij omvat ook participanten die tot de finale-vraagcategorieën worden gerekend zoals, naast huishoudens, ook overheidsbestedingen, capaciteitsvergrotende bedrijfsinvesteringen en exporten. Hiernaast bestaan er verschillende typen multisectorale modellen, waarvan elk type weer andere eigenschappen beklemtoont. Ze hebben echter alle gemeen dat hun kerngrootheden bestaan uit aggregaten op meso-niveau. De modeltypen zelf variëren naar de mate waarin ‘*rigiditeiten*’ of ‘*stabiliteiten*’ aanwezig worden verondersteld tussen deze aggregaten. Productiefuncties vormen een voorbeeld van een rigiditeit in een multisectorale context. In termen van de hierna te behandelen modellen b.v. betekent dit dat de elementen van bepaalde matrixkolommen geïnterpreteerd worden als inputfactoren in een productiefunctie. Bij de hierna kort te bespreken limitationele of Leontief productiefuncties houdt dat in dat een vaste verhouding wordt gepostuleerd tussen bepaalde elementen in de matrixkolom. Dat wil zeggen, de inputfactoren worden gebruikt in een onderlinge verhouding die niet afhankelijk is van schaalgrootte of compositie van andere modelgrootheden. Het is een nog altijd punt van discussie of b.v. ook afzet- en verkooppatronen een dergelijke vast patroon vertonen. Indien men van mening is dat dat wel zo is, dan is dat een additionele ‘rigiditeit’. Naast rigiditeiten in de sfeer van productiefuncties, zullen wij ook de aanwezigheid van andere, meer institutioneel bepaalde rigiditeiten veronderstellen. Het gaat dan b.v. om constante of redelijke constante patronen in bepaald consumptiegedrag en in het beleid ten aanzien van werkgelegenheid. We geven nu een kort overzicht van de wijze waarop economische netwerken worden gemodelleerd. Het vertrekpunt vormt de notie van een industrie of sector.

Industrieën zijn b.v. verschillende typen landbouw, lichte en zware industrie en vele typen diensten. Stel we gaan uit van een industrie genaamd ‘consumentenelectronica’. Statistische bureaus verzamelen per gebied (zoals een land of een regio daarbinnen) informatie over alle bedrijven die gerekend worden tot een bepaalde sector (zoals de consumentenelectronica). Vervolgens wordt, volgens bepaalde, internationaal afgesproken uitgangspunten, voor alle bedrijven in deze sector de informatie geaggregeerd naar ‘input’, de aankoop van bedrijven in andere sectoren, en naar ‘output’, de leveringen aan bedrijven in andere sectoren. Indien we deze informatie ordenen in een kruistabel, dan resulteert dat, per sector, in een kolom van inputs en een rij van outputs. Als dit voor alle industrieën gebeurt, heeft men de beschikking gekregen over een zogeheten *input-output tabel*. Daarmee heeft men dan een overzicht van de onderlinge leveringen in de gehele economie in een bepaald jaar. De tabel is volledig als zij opgesteld is inclusief kolommen die de zogeheten finale leveringen aan gezinnen en overheid, de investeringen van bedrijven en de export weergeven. Corresponderend hiermee bevat een volledige tabel ook rijen waarin de lonen en salarissen, de afschrijvingen, importen en de belastingen en subsidies zijn weergegeven. De tabel weerspiegelt een *evenwicht* in de zin dat de totalen van overeenkomstige rijen en kolommen gelijk zijn.

Men maakt de stap naar een *input-output model* als men verder aanneemt dat bepaalde onderlinge verhoudingen (redelijk) constant zijn over een aantal jaren, de hierboven al genoemde rigiditeiten (hoofdstukken 3 en 5). Heeft men deze gelocaliseerd, dan heeft men een uitgangsbasis verkregen om de effecten van veranderingen in bepaalde grootheden door te rekenen. In alle typen input-output model staan de sectorale inputs (de kolommen in de input-output coëfficiënten matrix) centraal. Zij worden geïnterpreteerd in termen van een zogeheten limitationele of Leontief *productiefunctie*, waarin de verhoudingen tussen de input categorieën onafhankelijk zijn van omvang en aard van de finale vraag. Deze aanname geeft de noodzakelijke stabiliteit aan de coëfficiëntenmatrices, en maakt het mogelijk om de consequenties van wijzigingen in de finale vraag met behulp van scenario's door te rekenen. Er is nog een ander punt hier van belang. Als gezegd, er bestaan nauwelijks modellen die gebouwd zijn rond het *verbreken* van onderlinge betrekkingen. De kern van een ramp zoals wij die wilden modelleren is juist het verbreken van de interne relaties. Dit betekent dat wij terug moesten gaan naar de onderliggende basisideeën. In ultieme zin is een input-output model niets anders dan een op een bepaalde manier geordende verzameling productiefuncties gekenmerkt door constante verhoudingen. Op deze eigenschap met name is een beroep gedaan bij het modelleren van de gevolgen van een ramp.

Centraal verder is het onderscheid tussen endogene variabelen (waarvan de waarde door het model wordt bepaald), en exogene variabelen (waarvan de waarde door factoren buiten het model wordt bepaald). In een *open* input-output model worden de waarden van de finale bestedingen als exogeen genomen. Dit opent de mogelijkheden tot het bepalen van de impact van b.v. Keynesiaans vraagstimulerend beleid in termen van de vereiste productieverhoging in bepaalde sectoren, en de daarmee verbonden werkgelegenheid. Het model biedt hierbij tevens de mogelijkheid tot het bepalen van prijseffecten. In *gesloten* input-output modellen worden de onderlinge verhoudingen tussen alle sectoren (in overeenstemming met een bepaald evenwichtsbegrip – waarover later meer) endogeen bepaald, waarbij vaak slechts de niveaus exogeen zijn.

Het input-output model is eveneens gebaseerd op het gegeven van de economische kringloop als weergave van het netwerkidee. Voor ons is van belang dat in open Leontief modellen de kringloop wordt gekenmerkt door vastliggende verhoudingen tussen de sectorale productieniveaus, gegeven de exogeen bepaalde finale vraag. Voor gesloten modellen ligt dit anders, zie hieronder.

Het input-output model is een multisectoraal model. Er zijn echter meerdere typen multisectorale modellen, elk met een eigen theoretische grondslag. De modellen van Leontief zijn waarschijnlijk het meest bekend, maar er zijn een aantal andere. Ook bestaan er binnen de op Leontief georiënteerde groep van modellen weer verschillende subtypen. Een alternatief is het model van Von Neumann. In de opzet hebben beide modeltypen veel gemeen. De basis b.v. is de productiefunctie, die op een gestandaardiseerde manier input en output van een bepaald proces weergeeft. Bij Leontief handelt het dan om productieprocessen die één enkel product of output produceren, waarbij tevens geldt dat elk product slechts op één karakteristieke manier geproduceerd kan worden. Bij Von Neumann kunnen dat meerdere outputs tegelijk zijn, terwijl tevens Leontiefs één op één betrekking ontbreekt. Hiertegenover staat dat Leontiefs model empirisch van zeer grote betekenis is. Er bestaat zeer veel empirisch materiaal waarbij opgemerkt moet worden dat ook de Nationale Rekeningen een input-output kern bezitten (al heeft die ook eigenschappen die aan Von Neumann herinneren).

We wilden een model dat in principe op elk gewenst aggregatieniveau kan opereren. Dat wil zeggen, een model waarin door aggregatie van kleinere eenheden, grotere eenheden tot stand kunnen komen; uiteraard wel met behoud van de onderlinge betrekkingen. De moderne systemen voor de compilatie van input-output tabellen laten, desgewenst, een grote mate van ruimtelijke disaggregatie toe. Dat wil zeggen, het is met een grote mate van betrouwbaarheid mogelijk om een ruimtelijke component toe te voegen aan de gebezigde productieparameters. De huidige geografische informatiesystemen (GIS) kunnen hierbij de noodzakelijke additionele informatie verstrekken. Dit is van groot belang bij het vaststellen van de omvang van een eventuele ramp voor wat betreft verlorengegane economische capaciteit. Het is momenteel b.v. mogelijk om met een grote mate van precisie de ontstane toestand 'op de grond' na een grote dijkdoorbraak weer te geven aan de hand van gedetailleerd kaartenmateriaal. De kaarten zijn gebaseerd op de kenmerkende eigenschappen van het land, zoals hoogteverschillen, fysieke barrières in zowel de stedelijke als de landelijke gebieden, enz., informatie die gecombineerd kan worden met gedetailleerde economische data (de hoofdstukken 5 en 7).

In de hoofdstukken 3 en 5 wordt het basis Leontief model geïntroduceerd. Hoofdstuk 3 doet dit in relatie tot het kringloopbegrip zoals dat in het basismodel zijn weerslag heeft gevonden. Geïntroduceerd worden de kernvergelijkingen [3.1] en [3.2]. Vergelijking [3.1] beschrijft de totale productie ($\mathbf{x}$) als de som van intermediaire leveringen ($\mathbf{Ax}$) en finale vraag ($\mathbf{f}$); een grafische interpretatie is gegeven in hoofdstuk 6 in context van homogene en niet-homogene schokken. De hiermee corresponderende werkgelegenheid, uitgesplitst over de industrieën, wordt gegeven door [3.2]. Het model beschrijft het intermediaire verbruik en de totale productie als een functie van de samenstelling en omvang van de finale vraag $\mathbf{f}$. Het model is veel gebruikt bij empirisch onderzoek om de impact van veranderingen $\Delta\mathbf{f}$ op het intermediaire verbruik ($\mathbf{A}\Delta\mathbf{x}$) en de totale productie ($\Delta\mathbf{x}$) te berekenen.

In hoofdstuk 6 bespreken we de modellering van de impact van de catastrofe. We gaan daarbij uit van een evenwichtssituatie vlak voor de catastrofe, gemodelleerd volgens Leontief. Dat wil zeggen, alle interne verhoudingen binnen de economie stemmen overeen met een bepaalde, gegeven finale vraag. De situatie kort na de catastrofe wordt in eerste instantie gemodelleerd in termen van gewijzigde sectorale productiecapaciteiten. Een deel van de bedrijven zal niet meer kunnen functioneren. Dat betekent dat voor de getroffen sectoren de bestaande outputniveaus naar beneden moeten worden bijgesteld. In ons model wordt uitgegaan van een capaciteitsverlies van $100\gamma_i$ procent voor een willekeurige sector i. Op dezelfde manier zal de bestaande werkgelegenheid eveneens naar beneden moeten worden bijgesteld. Omdat de γ_i's per industrie zullen verschillen, zullen in de onmiddellijke post-catastrofe periode de nog bestaande capaciteiten naar verwachting niet meer de interne verhoudingen bezitten die nodig zijn om aan de vraag te voldoen van diegenen die na de ramp nog een werkplek bezitten. Deze post-catastrofe situatie van interne disproporties wordt modelmatig weergegeven door de zogeheten '*Basic equation*', vergelijking [6.18]. Deze vergelijking 'lijkt op' een basis input-output vergelijking van het type [3.1]. Zij is het echter niet, omdat de geïmpliceerde input coëfficiënten geen bestaande technologieën voorstellen.

De Basic equation vormt het vertrekpunt voor de analyse van post-catastrofe hersteltrajecten. Vanuit dit vertrekpunt kunnen, vanzelfsprekend, vele trajecten worden ingezet. Op dit punt zal het getroffen land zich moeten realiseren wélk hersteltraject zij precies wil inzetten. Vanwege mogelijke onoverzichtelijkheid en disorganisatie tijdens de onmiddellijke post-catastrofe periode is het daarbij van groot belang dat het land reeds een portfolio bezit van eventueel beschikbare scenario's. Het is verder van groot belang dat er politieke overeenstemming bestaat over de richting waarin de reconstructie wordt gezocht. In termen van ons model betekent dat dat de getroffen economie enig inzicht moet hebben in de gewenste interne sectorale verhoudingen. We hebben gezien dat in de precatastrofe situatie de interne verhoudingen een functie waren van de finale vraag. Hier nu doemen twee problemen op, n.l. 1) is het in de nieuw ontstane situatie nog steeds zo dat samenstelling en omvang van de finale vraag nog altijd richtinggevend zijn? en 2) indien zo, zijn de gewenste proporties nog wel realistisch?

Bij de verdere discussie zijn wij uitgegaan van het gegeven dat het getroffen gebied kiest voor een ‘strategie’ om zo spoedig mogelijk weer een levensvatbare economie te hebben. Wij hebben die gedefinieerd in termen van een kringloop gebaseerd op intern consistente productie-elementen. Uitgaande van een scenariokeuze gebaseerd op een bepaalde finale-vraagcompositie dient zich ook hier weer een keuze aan. Indien de economie er voor zou kiezen om de finale vraag te wijzigen, b.v. als antwoord op de gewijzigde productiemogelijkheden, dan verandert daarmee ook het patroon van vereiste sectorale capaciteiten. De zo gewenste interne afstemming tussen mogelijkheden en gewenste netto productie kan in een dergelijke configuratie misschien gerealiseerd worden. Waarschijnlijk is dit echter niet, en moet er gericht gestuurd worden om de juiste proportionaliteiten te bewerkstelligen. De situatie wordt voor enkele gevallen grafisch weergegeven in de figuren van hoofdstuk 6 en later wiskundig in termen van het Von Neumann model, ditmaal in termen van een economische *contractie*. We ontmoeten ook hier weer een keuzeprobleem, waarbij we uit de vele mogelijkheden er één hebben gekozen, n.l. het herstel van de *status quo ante*. Dat wil zeggen, we hebben gekozen voor een finale-vraagcompositie van dezelfde samenstelling als voor de ramp. Hiermee ligt het model vast en kunnen eventuele berekeningen uitgevoerd worden.

In onze modelexercitie hebben we ons (louter) gericht op die activiteiten die gericht waren op het herstellen van de rol van het economische netwerk. Dat betekende dat we allerlei uiterst belangrijke activiteiten rond opruiming en herstel enkel meegenomen hebben voorzover die een rol spellen bij de gerichte reconstructie.

Modelmatig wordt, in hoofdstuk 6, het (open) model geherformuleerd in termen van het reële loon (real wage). Dit is mogelijk omdat het loon per sector, betaald in een monetaire eenheid, onmiddellijk door de werknemers wordt omgezet in de fysieke aankoop van een consumptiegoederenbundel. Omdat alle werknemers geacht worden dezelfde preferenties te bezitten én hetzelfde loon ontvangen, kan aan elke industrie een reëel loon worden toegerekend evenredig aan de werkgelegenheid die de sector biedt. Wiskundig betekent dit dat we een nieuwe input coëfficiënten matrix krijgen, **M**, die de som is van matrix **A** en van een nieuwe matrix, **H**, die het reële loon weergeeft. Het model krijgt hierbij de wiskundige vorm van een gesloten Leontief model, reeds geïntroduceerd in [3.6]. In de secties 6.6 en 6.7 wordt aangetoond dat dit model ook geïnterpreteerd kan worden als een speciaal geval van Von Neumann’s befaamde groeimodel.

Bij deze interpretatie is de samenstelling van de finale vraag van belang. Indien deze in de volgende perioden niet verandert, en als ook de technologieën niet veranderen, verandert er qua verhoudingen niets in de economie. In dat geval kan het open Leontief model ook geïnterpreteerd worden als een gesloten (Leontief) model. Echter, een dergelijk Leontief model is ook te zien als een Von Neumann groeimodel met speciale ‘Leontief’ kenmerken (n.l. enkelvoudige productie en geen alternatieve productieprocessen per goed). Dit bijzondere model is ons uiteindelijke model geworden omdat het op een directe manier contractieverschijnselen modelleert.

Hoofdstuk 7 bespreekt eerder empirisch onderzoek naar een grote overstromingsramp in het hoogontwikkelde westelijk deel van Nederland. Het bestaande watermanagement systeem wordt in het kort besproken in termen van dijkringen en veiligheidsmaatstaven. Dit is de omgeving waarin de hypothetische case van een dijkdoorbraak bij Rotterdam is geplaatst. De gekozen methodologie van het onderzoek is gebaseerd op een GIS analyseapparaat gecombineerd met een data transformatiesysteem. Informatie met betrekking tot werkgelegenheid wordt ‘vertaald’ in een vorm die een band legt met input-output data. We hebben de rekenexercitie herhaald tegen de achtergrond van ons nieuw ontwikkelde Leontief-Von Neumann model. We bediscussiëren de verschillende aggregatiemethodieken die ter beschikking staan, en gaan in op de methodologische achtergrond van alternatieve uitkomsten.

Hoofdstuk 8 beschrijft een aantal aspecten van de actuele situatie in ons land. Het blijkt dat een paradigmawijziging langzamerhand zichtbaar wordt. De aloude wijsheid om het water als de belangrijkste vijand te zien, een wijsheid die teruggaat op een eeuwenoude traditie, verliest geleidelijk aan haar macht. Het huidige systeem van bescherming tegen het water gaat terug op het Delta Plan, opgesteld na de vernietigende vloed van 1953. De calculaties rond het Deltaplan gebaseerd op het werk van Van Dantzig waren gericht op het minimaliseren van overstromingskansen in een dynamische context van gerichte investeringen. Hier vinden we de aanzetten tot een wijziging in de grondhouding door een nieuw type risico management. Dit is een reactie op de grote vlucht die de Nederlandse economie heeft genomen gedurende de laatste decennia. Die betekende dat datgene wat beschermd werd door het dijkenstelsel een steeds hogere economische waarde kreeg, de variabele E in de formule $R = P \times E$. Hierbij staat R voor het economische risico dat wordt gelopen en P voor de waarschijnlijkheid op een overstroming. De variabele P heeft momenteel wel zijn laagste niveau bereikt. Echter, de waarde van E stijgt voortdurend door de (nog altijd) exponentiële ontwikkeling. Dit betekent dat het risico, het product van P en E, voortdurend stijgt. Dit vraagt om nieuw beleid bij een aantal fundamentele kwesties.

In het laatste hoofdstuk sluiten we af, en zien we vooruit. We hebben nogmaals het belang beklemtoond van een zo veel mogelijk uniforme methodologie bij onderzoek naar catastrofes. We hopen dat ons onderzoek daartoe een bijdrage kan leveren. Een aantal punten dient, uiteraard, nader te worden bekeken in andere contexten. Onze focus op de economische kringloop en de interpretatie van een ramp in termen van een verstoring van die kringloop vormt een dergelijk punt. Ook het belang dat we toegekend hebben aan bepaalde rigiditeiten in de economische en sociaal-maatschappelijke structuur van een land vraagt om nader onderzoek, evenals de verdere uitwerking van het kostenbegrip, nu gelieerd aan de verstoorde kringloop. Van groot belang lijkt ons het ontwikkelen van een aantal scenario’s voor de onmiddellijke post-catastrofe periode. Deze scenario’s zouden dan, idealiter, moeten worden opgesteld in de context van nationale besluitvorming rond thema’s ten aanzien waarvan duidelijke keuzes moeten worden gemaakt. Moderne inzichten rond risico management en de risk society zullen hier een centrale rol spelen.

Tenslotte, we hebben aangegeven dat we ook veel punten niet of niet uitvoerig hebben kunnen behandelen. Wellicht het meest belangrijke punt daarbij is dat onze methodologie, ontwikkeld in de Leontief-Von Neumann traditie, zeker nadere toetsing vereist, waarbij een dergelijke toetsing ook meteen een toets is voor de flexibiliteit van het input-output raamwerk. Kernpunt hier zal in ieder geval zijn onderzoek naar de aanwezigheid en de aard van rigiditeiten –van welke aard dan ook- in de moderne, multisectorale wereld.

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