1 Introduction

1.1 Problem Definition and Objectives of This Work

In recent decades the frequency and severity of natural disasters increased.[1] This development is accompanied by an increase in catastrophe related economic losses and is assumed to continue for the foreseeable future if effective disaster mitigation efforts are omitted.[2] Due to the massive destruction of physical assets the basis for economic losses are generally reconstruction costs, which must be raised after a catastrophe to restore the original state of buildings and infrastructure. Thus, the need for reconstruction together with the financial influx from disaster relief and insurance payouts might create a boom.[3] As a consequence some economic sectors might even experience positive effects after natural disasters, e.g., retail and construction.

The sudden increase in demand is often confronted with a constant supply of relevant goods and labor. As a consequence, significant price effects for reconstruction labor and material are expected, which should be taken into account in the forecast of economic and insured losses of future catastrophes. Thus, to estimate future costs it is not appropriate to apply the expected price level under normal conditions. In literature such inflation or price effects are known as the "Demand Surge" effect and "occur[s] when the demand for products and services exceeds the regional capacity to efficiently supply them. The additional costs for these products and services are directly passed on to the consumer

[1] See Kunreuther and Michel-Kerjan (2009).
[2] See Pielke (2005) and Pielke et al. (2008).
[3] See Guimaraes et al. (1993).

(and the insurer)".[4] To provide some anecdotal evidence, it is estimated that the Demand Surge effect due to Hurricane Katrina is in the range of 30% to 40%, resulting in a significant increase in repair costs.[5] Moreover, Demand Surge is neither a new phenomenon nor limited to a particular region or a particular type of catastrophe.[6] First evidence of Demand Surge date back to the fourteenth century England, it has been observed all over the world and for several catastrophe types, like earthquakes, floods, hurricanes or wildfires.[7]

Against this background, it is quite remarkable that only a few contributions in the literature address this phenomenon. The scientific literature considers Demand Surge exclusively on a qualitative level or only for a specific catastrophe type or event; universally valid quantitative models for Demand Surge have not been published. In contrast, the main catastrophe modeling companies in the world consider the Demand Surge effect within the framework of modeling direct losses due to catastrophes. However, the models of these companies are not publicly available. In particular, it is not clear which empirical results underlie their models. Therefore, this thesis investigates the impact of catastrophe induced exogenous shocks to the local reconstruction industry. The most important research questions addressed are the following:

- How can Demand Surge effects be measured?
- Under which conditions do natural disasters lead to Demand Surge effects?
- How strong is the Demand Surge effect?

The above stated three research questions are studied with empirical analyses. First, some fundamentals of catastrophe risk and basics regarding the Demand Surge effect are presented. On the basis of these considerations two empirical research projects are carried out. The first analysis deals with the question how Demand Surge effects can be measured and identifies key drivers of this phenomenon. The second empirical analysis further

[4] See EQECAT (2005).
[5] See Munich Re (2006b).
[6] See Olsen and Porter (2011b).
[7] See Olsen and Porter (2010).

examines influencing factors and aims to identify which economic conditions promote the occurrence of Demand Surge effects in the aftermath of natural disasters.

The results should be beneficial for various market participants and should be the basis for a quantitative assessment of Demand Surge for future catastrophes. Among others, governments have to deal with rising economic damages and a deep understanding of Demand Surge is necessary to apply appropriate price regulations. Insurance companies are confronted with inflating claim levels and should consider Demand Surge effects with respect to premium calculation and determination of economic capital. Finally, building contractors should use this information for future capacity planning.

1.2 Course of Investigation

To analyze the research questions stated above this thesis is structured as follows. Fundamentals of catastrophe risk are discussed in Chapter 2. First, Section 2.1 provides definitions of the term disaster and aims at categorizing and defining costs of disasters. Next, the risk management chain of the International Graduate College 802 (IGC 802) is explained in detail in Section 2.2. This will be the frame of reference throughout this thesis and aims at defining a common standard for risk management discussion in an interdisciplinary context.

Chapter 3 deals with Demand Surge in general. First, general definitions are provided in Section 3.1. It is noteworthy that despite the importance of the Demand Surge effect no unique term or definition exist. Rather, each involved market participant has his own wording and understanding of this phenomenon. Section 3.2 provides an overview of events that are known to have produced Demand Surge in the past, before an overview of the regulatory framework is provided in Section 3.3. This section describes the coverage of Demand Surge by standard insurance contracts in the United States and Germany. Next, Section 3.4 deals with the impact of Demand Surge on labor and material prices. To this end, some theoretical considerations and examples are provided regarding the reaction of labor and material prices to the occurrence of natural disasters. The following

Section 3.5 gives an overview of the current state of the art in Demand Surge modeling. At the beginning, commercial Demand Surge models developed by the leading catastrophe modeling companies in the world are presented. Unfortunately, all model providers withhold details as intellectual property. As a consequence, the modeling results remain partly opaque. In addition, public and scientific Demand Surge models are described. Finally, Section 3.6 introduces our measurement approach of Demand Surge. This will be our theoretical framework and starting point for the following Chapters 4 and 5.

The empirical analyses in Chapter 4 aim to determine possible influencing factors on the Demand Surge effect. This can be either catastrophe specific or macroeconomic variables. Moreover, an approach to quantify the Demand Surge effect in an empirical setting is presented. Therefore, two of the three research questions stated above are addressed in this chapter. The fundamentals are presented in Section 4.1. Based on common assertions of the literature hypotheses concerning influencing factors on Demand Surge are derived in Section 4.2. The empirical analyses are established in Section 4.3. First, the empirical approach to quantify Demand Surge effects is presented. Second, the formulated hypotheses are tested based on two different data sets containing detailed information regarding natural catastrophes in the United States. In this context, the data selection and corresponding summary statistics are presented, too. The main results of this chapter are subsumed in Section 4.4.

Chapter 5 build upon the empirical setting in the previous chapter but with a focus on the economic perspective. Again, the fundamentals and research question are presented in Section 5.1. Due to the slightly changed focus in this chapter Section 5.2 provides a review of the literature regarding the impact of exogenous shocks on local labor markets and the corresponding wage effect. Afterwards, Section 5.3 describes the influence of Demand Surge on several possibly affected market participants. A slightly adapted set of hypotheses is introduced in Section 5.4. Section 5.5 describes the empirical strategy and issues related to the data used in the upcoming analyses. The empirical analyses itself are content of Section 5.6. First, influencing factors on the occurrence of a significant Demand Surge effect are analyzed, i.e., economic conditions that promote Demand Surge effects are identified. Second, the subset of observations with significant Demand Surge effects is analyzed in detail. Finally, the key findings of this chapter are summarized in Section 5.7.

Chapter 6 summarizes the results of the preceding chapters and addresses still unsolved research questions in the context of Demand Surge modeling.

2 Fundamentals of Catastrophe Risk

2.1 Economics of Natural Disasters

When describing and analyzing the impact and consequences of natural and man-made disasters it is of crucial importance to define important terms often used in the press and the scientific literature to ensure an unique understanding of these terms. Against this background, the main challenge of this section is to answer the following two questions:

- What is a disaster?
- How can costs of disasters be categorized and defined?

Therefore, the first task will be to provide different definitions of the term disaster. Almost every provider of disaster data, inspecting authority, (re-)insurance company, and state has his own definition. Very general disasters are "low-frequency, high-severity" events that lead to a perturbation of the economic system. According to the International Disaster Database EM-DAT[8] a disaster is defined as an event that fulfill at least one of the following criteria: (1) ten or more people reportedly killed, (2) 100 or more people reportedly affected, (3) declaration of a state of emergency, or (4) call for international assistance.[9] In contrast, Swiss Re defined a disaster in 2013 as an event that exceeded one of the following thresholds based on the type of disaster given in Table 2.1.[10]

[8]EM-DAT: The OFDA/CRED International Disaster Database - www.emdat.be - Université Catholique de Louvain - Brussels - Belgium.
[9]See Scheuren et al. (2008, p. 2).
[10]See Swiss Re (2014, p. 2).

Table 2.1: Swiss Re Disaster Definition Criteria 2013.

Insured losses (threshold in million US-$)	
Maritime disasters	19.3
Aviation	38.6
Other losses	48
or Total economic losses (threshold in million US-$)	
	96
or Casualties	
Lost or missing lives	20
Injured	50
Homeless	2,000

An overview of the world's disaster databases and their corresponding disaster definition criteria is provided by the Global Risk Information Platform (GRIP).[11] This overview is a result of the collaboration between the Centre for Research on the Epidemiology of Disasters (CRED) and the Global Risk Identification Program (GRIP). The Global Risk Information Platform is hosted by the United Nations Development Programme (UNDP), and financially supported by the United States Agency for International Development (USAID).

Hallegatte and Przyluski (2010) propose a categorization and definition of the different types of cost of a disaster, and, hence, should answer the second question.[12] At first, direct and indirect losses have to be distinguished. **Direct losses** describe the immediate consequences of a disaster, like a hurricane or an earthquake. These losses can be subdivided into direct market losses and direct non-market losses. Direct market losses refer to losses of assets, e.g., damaged buildings and/or infrastructure, or losses of services. These direct losses can be estimated quite easily, as these goods and services are traded on markets, and, therefore, can be estimated as the reconstruction or replacement costs. In contrast, direct non-market losses include loss of lives, damage to the cultural heritage or the natural environment. For all these damages it is nearly impossible to quantify the

[11] See http://www.gripweb.org/gripweb.

[12] Alternative but mostly similar categorizations and definitions can be found in ECLAC (2003), Pelling et al. (2002), and Committee on Assessing the Costs of Natural Disasters, National Research Council (1999).

monetary damage, as these assets are not traded on markets. A recent example would be the impact of the explosion and sinking of the Deepwater Horizon oil rig to the ecosystem in the Gulf of Mexico in 2010. Finally, BP paid billions of USD but it is still questionable if such a damage has a fair price at all. **Indirect losses** refer to the consequences of disasters and not to their immediate impact. Disasters often lead to a disruption of water and electricity supplies, and, therefore, lead to business interruptions. As a consequence, output losses arise and lead to a reduction in the total value added. But also negative losses might occur, e.g., during the reconstruction boom following the disaster. When considering both direct and indirect losses one can observe non linearity in **total losses**, which are defined as the sum of direct and indirect losses.[13] Figure 2.1 shows the evolution of indirect losses as a function of direct losses. Once direct losses reach 220 billion US-$ indirect losses coincide with direct losses, and, therefore, total losses are twice as large as direct losses. Thus, Hallegatte (2008) suggests that direct losses are not a good measure of disaster consequences and are inappropriate for risk management purposes. In addition, Hallegatte et al. (2007) define a measure called "Economic Amplification Ratio" (EAR) which is defined as the ratio of total losses to direct losses. To conclude, it is always important to keep in mind who publishes a disaster report and with which purpose.

In recent decades the frequency and severity of natural and man-made disasters show a growing trend, as presented in Figures 2.2 and 2.3. Despite the occurrence of mega catastrophes like Hurricane Katrina in the United States or the Tohoku earthquake in Japan during the last years, even more destructive events are thinkable in the foreseeable future, at least if effective disaster mitigation efforts are omitted.[14] In addition, analytic simulations already underlie the fear that even more destructive catastrophes might occur in the future.[15] The main drivers of the increasing severity of natural disasters are the increase of population and accumulation of assets in disaster prone areas. For example, Kunreuther and Michel-Kerjan (2009) state that during the years 1970 to 2010 the population of the state Florida grew from 6.8 million to approximately 19.3 million, which means an increase of more than 180%.

[13] See Hallegatte (2008, p. 792).
[14] See Pielke (2005) and Pielke et al. (2008).
[15] See Banks (2004).

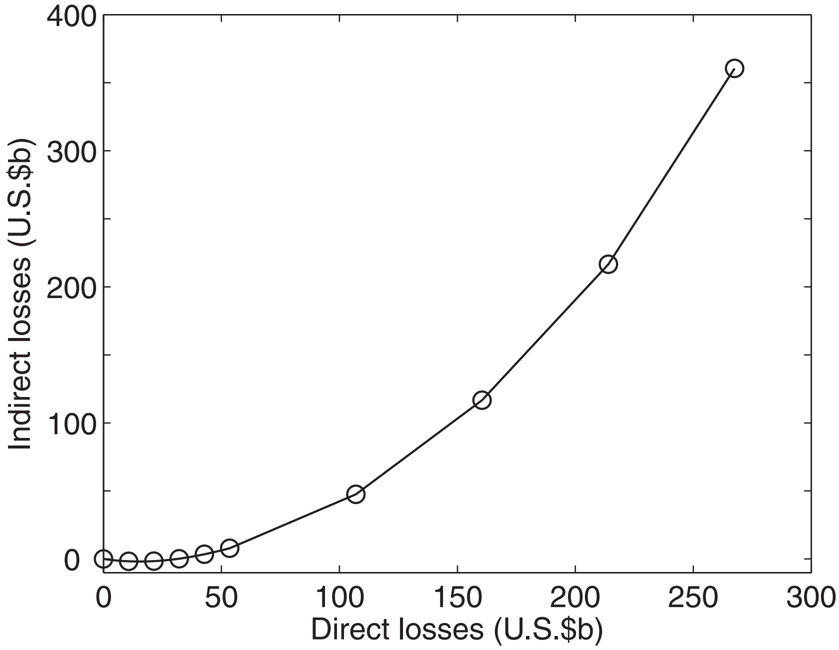

Figure 2.1: Indirect Losses as a Function of Direct Losses. Source: Hallegatte (2008).

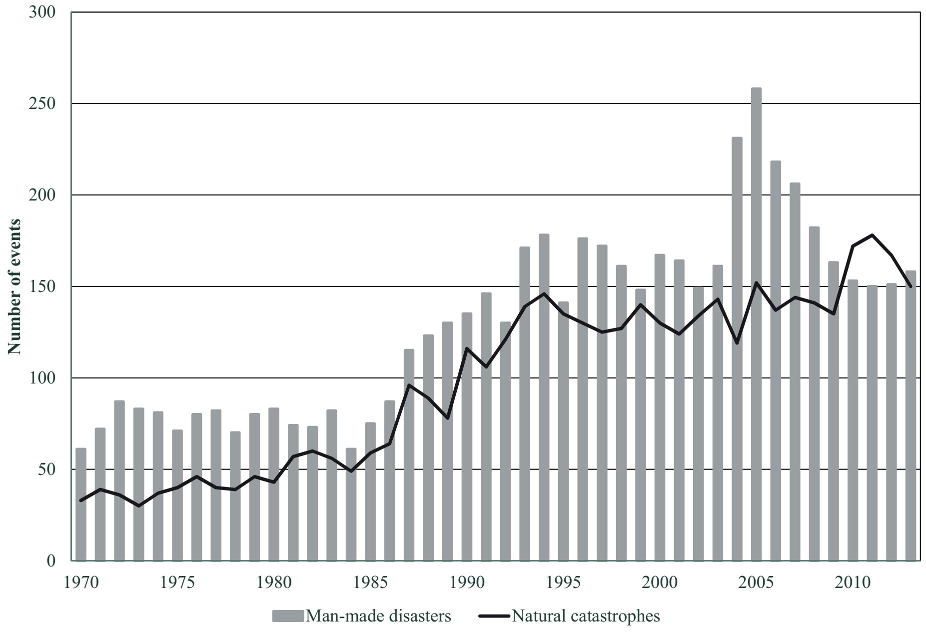

Figure 2.2: Number of Catastrophe Events 1970-2013. Source: Swiss Re (2014).

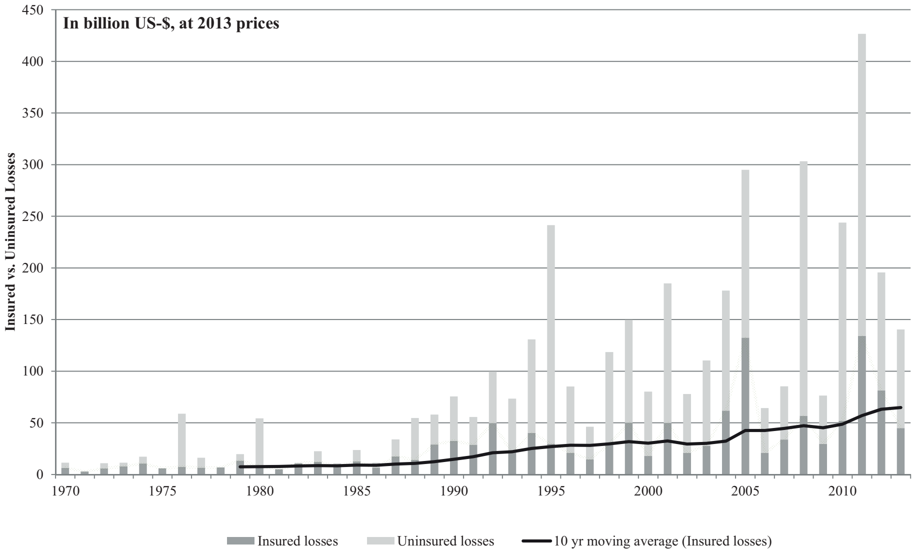

Figure 2.3: Insured vs. Uninsured Catastrophe Losses 1970-2013. Source: Swiss Re (2014).

Pielke et al. (2008) conducted a study in order to normalize hurricane damages in the United States for the time period 1900-2005. The original direct market losses were updated to 2005 using two different approaches. The first methodology was introduced by Pielke and Landsea (1998) and adjust for changes in inflation, wealth, and population. In contrast, the second approach was applied first by Collins and Lowe (2001) and adjust for changes in inflation, wealth, and housing units. Surprisingly, Katrina is not the costliest event ever. The Great Miami Hurricane in 1926 would result in direct market losses of 157 billion US-$ (Pielke/Landsea approach) or 139.5 billion US-$ (Collins/Lowe approach), much larger than the 81 billion US-$ in direct market losses of Hurricane Katrina. According to risk management theory protection against such mega catastrophes is most valuable.[16] Nevertheless, insurance claims regarding Hurricane Katrina only add up to 46.3 billion US-$ while the direct losses amount to 158.2 billion US-$ according to EM-DAT.[17] Figure 2.3 visualizes the discrepancy between insured and uninsured losses and it has to be noted that this under-insurance problem can even been observed in highly insured countries like the United States.[18] In addition, insurers themselves have to cope with rising insured losses. For example, the aggregate losses of Hurricanes Hugo (1989),

[16] See Froot (2001).
[17] Insurance claims data stem from Kunreuther and Pauly (2009, p. 2).
[18] See Cavallo and Noy (2010, p. 23).