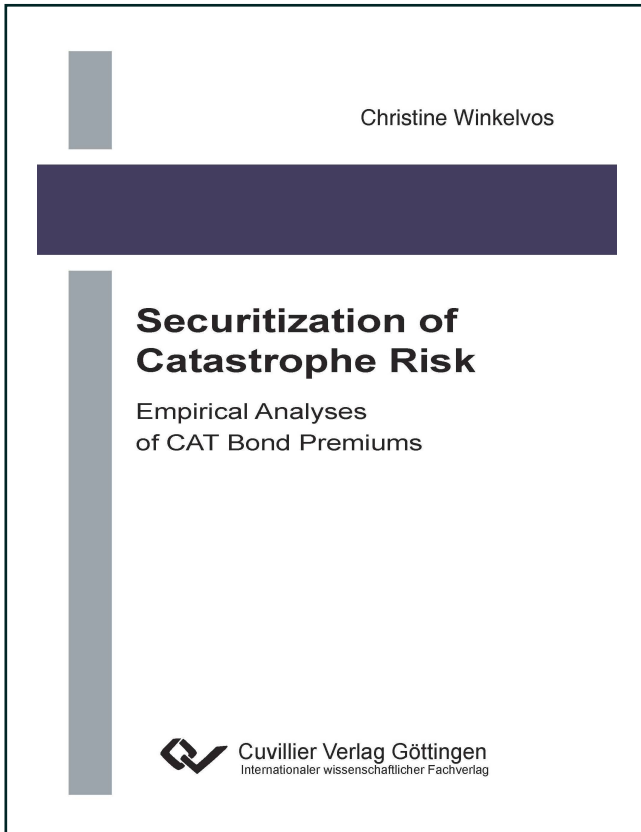




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Securitization of Catastrophe Risk
Empirical Analyses of CAT Bond Premiums



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1 Introduction

1.1 Problem Definition and Objectives of This Work

Natural catastrophes have always been feared by mankind due to their devastating impact and their unpredictability. They rarely occur but the outcome can be very severe. The impact of natural catastrophes is measured either in terms of fatalities or in terms of economic consequences. From 1980 to 2011 the most fatalities induced by natural catastrophes have been recorded in Asia followed by Africa with 1,176,000 and 608,000, respectively. From an economic point of view, the severity of natural catastrophes can be measured in terms of losses for the insurance industry. According to insured losses, the most severe catastrophes in the above time period happened in America with USD 566,000 million and in Europe with USD 146,000 million.¹

Insurance companies provide among others insurance for individuals or firms against catastrophe risks. In order to be able to cover such risks, they transfer parts of these risks to reinsurance companies via traditional reinsurance. In short, reinsurance companies are able to cope with higher risks than insurance companies because of regional diversification and other risk management instruments. However, even reinsurance companies are affected heavily if a severe catastrophe like hurricane Katrina in 2005 or the Tohoku earthquake in 2011 occurs. As a consequence of such events, capital capacity for new subscriptions is short. Therefore, it is conceivable that the demand for (re)insurance of catastrophe risk may not be satisfied or the prices for catastrophe (re)insurance products on offer may be very high.

In addition, it has been observed during the last decades that both the trend of numbers of catastrophes and the trend of insured losses due to catastrophes are positive. Correspondingly, natural catastrophes are expected to induce even heavier insured losses in the future.² These developments are very challenging for the insurance industry. It has to be considered how natural catastrophes can still be insured without putting the companies' solvency at risk. Furthermore, it is questionable whether enough insurance capital is available in order to cover increasing catastrophe losses.

¹The information has been provided by the NatCatSERVICE of Munich Re in 2012.

²See, for instance, Pielke et al. (2008).



Against this background, catastrophe bonds (CAT bonds) have been invented in the 1990's. CAT bonds securitize catastrophe risk by transferring the risk from (re)insurance markets to financial markets. Thus, additional capital is provided to the (re)insurance market and the above mentioned problems that arise in the context of capacity shortage are accounted for. An important condition for successful trading of securities is the determination of accurate prices. In the case of catastrophe risk, common financial pricing models may not be appropriate due to incompleteness of the market. Hence, a challenging question is how to price CAT bonds most accurately. Typically, the investors demand a risk premium for the assumption of risk. Because CAT bonds are not standardized, there can be various factors that influence the premium. Consequently, the CAT bond premium is an important parameter of the CAT bond price.

There are several approaches to model the determination of CAT bond premiums. In general, premium calculation models explain the relationship between the expected loss, and the premium. Most of the existing approaches use a linear relationship between the premium, the expected loss, and, in some cases, further premium determining factors. Another approach uses a loglinear relationship between the premium and the expected loss. Furthermore, there are more sophisticated models that determine the premium by economically interpretable transformations and thus have positive theoretical properties. To the best of our knowledge, the literature lacks a comparison of the different premium calculation models for CAT bonds. Thus, it is not possible to presume which is the most accurate model to explain and to predict CAT bond premiums. Moreover, it is not apparent which factors determine the premiums of CAT bonds. In the literature there are only few empirical studies that analyze on relatively small data sets which factors determine the CAT bond premium. In addition, it is widely unknown how CAT bond premiums react to natural catastrophes and particularly to financial crises.

Against this background, the most important research questions that arise in connection with the determination of CAT bond premiums are the following:

- Which of the existing premium calculation models is the most accurate one in order to explain and to predict CAT bond premiums?
- What are the factors that determine CAT bond premiums?
- How are CAT bond premiums affected by natural catastrophes and financial crises?

This thesis is devoted to these research questions through empirical analyses. In the beginning, the theoretical framework for the empirical analyses is presented. This includes the basic mechanisms of (re)insurance, CAT bonds as well as premium calculation principles that can be applied to CAT bonds. Building on that, empirical analyses are established that analyze the research questions. The first



empirical analysis deals with a model comparison in order to identify the most accurate premium calculation model for CAT bonds. The second empirical analysis further examines the most accurate model in order to verify premium determinants and to analyze the impact of natural catastrophes and the recent financial crisis on CAT bond premiums.

1.2 Course of Investigation

In order to analyze the research questions mentioned above, the course of investigation is as follows. Chapter 2 deals with the management of catastrophe risk. First, the trend of catastrophes and the impact of catastrophes in terms of insured losses is analyzed in Section 2.1. Thereby, it becomes apparent that catastrophe risk management is of utter importance for (re)insurance companies in order to preserve the company's solvency in any situation. Section 2.2 describes catastrophe risk management according to the definition of the International Graduate College 802. Furthermore, the special case of risk management in insurance companies is considered. (Re)insurance is an important tool for catastrophe risk management to reduce the risk borne. In order to describe mechanisms of (re)insurance, in Section 2.3 the insurability of catastrophe risk is discussed. Against this background, traditional reinsurance and instruments of alternative risk transfer are examined.

An important instrument among alternative risk transfer are CAT bonds, which are presented in Chapter 3 in more detail. First, the mechanisms of a basic CAT bond are explained in Section 3.1, before an overview of the market development is provided in Section 3.2. On this basis, in Section 3.3 the most important details of CAT bonds, namely the insured peril, the applied trigger mechanism, and the cash flows, are presented. Having explained the functionality of CAT bonds, Section 3.4 introduces the risks arising in connection with a CAT bond and analyzes how these risks are examined. Thereby, especially the catastrophe risk assessment is described. The capabilities and advantages for both sponsor and investor are discussed in Section 3.5. In contrast, challenges that are connected to the trading of CAT bonds are analyzed in Section 3.6. Finally, the different pricing models for CAT bonds are presented in Section 3.7. Thereby the incompleteness of CAT bond markets is discussed. It is highlighted that the premium is a key parameter for the determination of the CAT bond price.

In general, the CAT bond premium can be determined by premium calculation principles, which are presented in Chapter 4. The chapter begins with the motivation and definition of premium calculation principles in Section 4.1. Next, in Section 4.2 it is derived that the net risk premium is the expected loss in order to avoid insolvency of an insurance company. Further, the necessity of a risk



premium is discussed. The connection of expected loss and risk premium can be modeled by premium calculation principles. These principles need to fulfill several properties, which are introduced in Section 4.3. On this basis, some important premium calculation principles are introduced. Basically, premium principles can be divided into basic principles and theoretical principles that are presented in Section 4.4 and Section 4.5, respectively.

The empirical analysis of Chapter 5 has the objective of answering the first research question stated above. The most accurate premium calculation model in order to explain and to predict CAT bond premiums shall be identified. The fundamentals of the empirical analysis are explained in Section 5.1. In Section 5.2, a literature review concerning premium calculation models for CAT bonds is presented. The empirical methodology is described in Section 5.3. Thereby, the models under consideration and the setting of the empirical analysis are described. Next, the data used in the empirical analysis is presented in Section 5.4. The empirical analysis is established in Section 5.5 in two different market situations. The main results of this chapter are subsumed in Section 5.6.

Having identified an accurate premium calculation model for CAT bonds in the previous chapter, Chapter 6 aims at further analyzing the respective linear model. The main objectives of this chapter are the identification of CAT bond specific and macroeconomic factors that influence the CAT bond premium. In addition, the impact of the recent financial crisis and of natural catastrophes on premiums is analyzed. First, the fundamentals and research questions of the empirical analysis are presented in Section 6.1. Second, hypotheses concerning influencing factors on premiums are derived in Section 6.2. We consider CAT bond specific hypotheses as well as macroeconomic and event hypotheses. Third, in Section 6.3 the data selection and corresponding summary statistics are presented. The empirical analysis is established in Section 6.4. Finally, the results of this analysis are subsumed in Section 6.5.



2 Management of Catastrophe Risk

2.1 Definition and Impact of Catastrophes

In general, a catastrophe can be defined as “an event causing great damage or suffering”. The term is originally Greek, meaning “overturning” or “sudden turn”³. In more detail, the International Disaster Database (EM-DAT) defines a catastrophe as an event, where either more than ten fatalities are reported, or more than a hundred people are affected, or a state of emergency has been declared, or international help has been called for.⁴ According to this definition, Table 2.1 presents the most severe catastrophes from 1950 to 2011 in terms of the deadliest and costliest events for the overall economy. In the field of insurance economics, various definitions for a catastrophe exist. Swiss Re (2012, p. 2) defines several thresholds for catastrophes. For instance, insured losses for maritime catastrophes that are larger than USD 18 million define a catastrophe.⁵

It is often stated in the literature that catastrophes are so called “low frequency – high severity” events, since the events are usually quite rare.⁶ However, in case of occurrence, catastrophes may cause severe losses that can exceed the (re)insurance market’s capacity significantly.⁷ Catastrophes are often divided into natural catastrophes and man-made catastrophes. While natural catastrophes comprise all events which are caused by natural forces, e.g. windstorms, earthquakes, or floods, man-made catastrophes refer to events which are directly caused by human behavior, e.g. ecological disasters, road accidents, or terrorism.⁸

³Definitions according to Soanes & Hawker (2008).

⁴See the homepage of EM-DAT: <http://www.emdat.be>.

⁵The NatCatSERVICE of Munich Re 2012 defines a catastrophe according to the United Nations by means of the following criteria: international help is necessary, over a thousand fatalities are reported, over one hundred thousand homeless people are reported, substantial losses arise for the overall economy, and extensive losses arise for the insurance industry. Furthermore, Lemor (2002) defines a catastrophe as an event where either more than EUR 1 billion loss for the overall economy arises or more than 0.5% of the Gross Domestic Product (GDP) in the affected country is lost.

⁶See, for instance, Litzenberger et al. (1996, p. 121).

⁷Most discussed properties and aspects of catastrophes and of catastrophe risk management lead to the same results for insurance as well as for reinsurance markets and companies. Thus, we refer to “insurance” in the following which comprises both insurance and reinsurance, unless otherwise indicated.

⁸See Kuck (2000, p. 7).



Table 2.1: Impact of Natural Catastrophes from 1950 to 2011.

Source: Munich Re (2010) and the NatCatSERVICE of Munich Re in 2012.

Deadliest Catastrophe Events			
Year	Event	Country	Fatalities
1970	Tropical cyclone, Floods	Bangladesh	300,000
1976	Earthquake	China	242,000
2010	Earthquake	Haiti	222,570
2004	Earthquake, Tsunami	Esp. Indonesia, Sri Lanka, Thailand, India	220,000
2008	Cyclone, Flood	Myanmar	140,000

Costliest Catastrophe Events for the Overall Economy			
Year	Event	Country	Overall losses (USD million)*
2011	Earthquake	Japan	210,000
2005	Hurricane Katrina	USA	125,000
1995	Earthquake	Japan	100,000
2008	Earthquake	China	85,000
1994	Earthquake	USA	44,000

*: Original values

Both man-made and natural catastrophes can cause severe losses for the insurance industry. So far, the highest peak in insured losses caused by a single event with an amount of USD 62,200 million was due to Hurricane Katrina in 2005.⁹ Table 2.2 provides an overview of the costliest events for the insurance industry measured in terms of insured losses from 1950 to 2011.

Table 2.2: Impact of Natural Catastrophes from 1950 to 2011 on the Insurance Industry.

Source: Munich Re (2010) and the NatCatSERVICE of Munich Re in 2012.

Year	Event	Country	Insured losses (USD million)*
2005	Hurricane Katrina	USA	62,200
2011	Earthquake	Japan	35,000 - 40,000
2008	Hurricane Ike	USA Caribbean	18,500
1992	Hurricane Andrew	USA, Bahamas	17,000
1994	Earthquake	USA	15,300

*: Original values

It can be observed that insured losses induced by natural or man-made catastrophes have significantly increased over the past 40 years.¹⁰ One reason for the

⁹Hurricane Katrina was also the most expensive natural catastrophe for the overall economy since records are available, see Table 2.1.

¹⁰See Figure 2.1.



great increase of insured losses is the increase of the number of catastrophe events as presented in Figure 2.2. In case of hurricanes, not only the number of events is increasing, but also the severity of events. Kunreuther & Michel-Kerjan (2009) state that the number of severe hurricanes doubled from the 1970s until 2005. There is a debate in the literature whether these changes can be related to climate change.¹¹ Another reason for increased insured losses is that there is an increase in population and economic development in endangered areas. For instance, Kunreuther & Michel-Kerjan (2009) point out that the population of the hurricane-threatened U.S.-state Florida grew from 6.8 million in 1970 to approximately 19.3 million in 2010. This argument also holds for earthquake events, where the number of events is stable but the insured losses increase due to the increase in population in endangered areas.

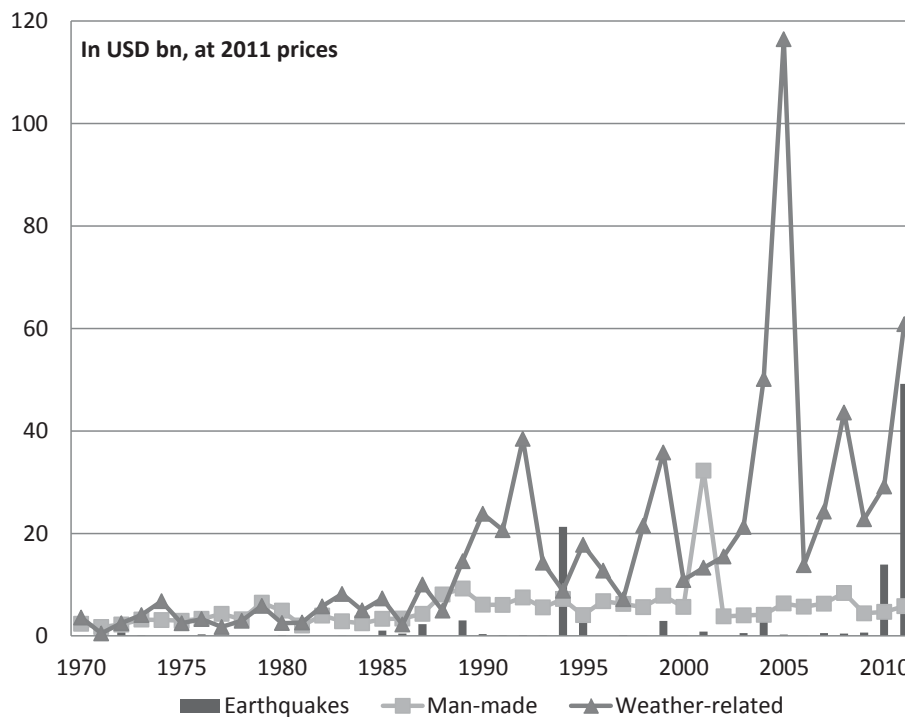


Figure 2.1: Insured Catastrophe Losses 1970-2011. Source: Swiss Re (2012).

Apart from that, high insured losses due to natural catastrophes result from a high density of insurance coverage. In Florida, for instance, almost 80 percent of insured objects are located close to the coast.¹² Munich Re (2012, p. 58) states that, in general, hurricane and storm events are much more insured than earthquake events. Thus, it can be observed that most of the costliest events for

¹¹Kunreuther & Michel-Kerjan (2009, p. 12) summarize the debate from the literature.

¹²See Kunreuther & Michel-Kerjan (2009, p. 9).



the insurance industry result from hurricane events. Instead, when analyzing the losses beyond the insurance market, it becomes apparent that the overall economy is even more affected by earthquake events.¹³

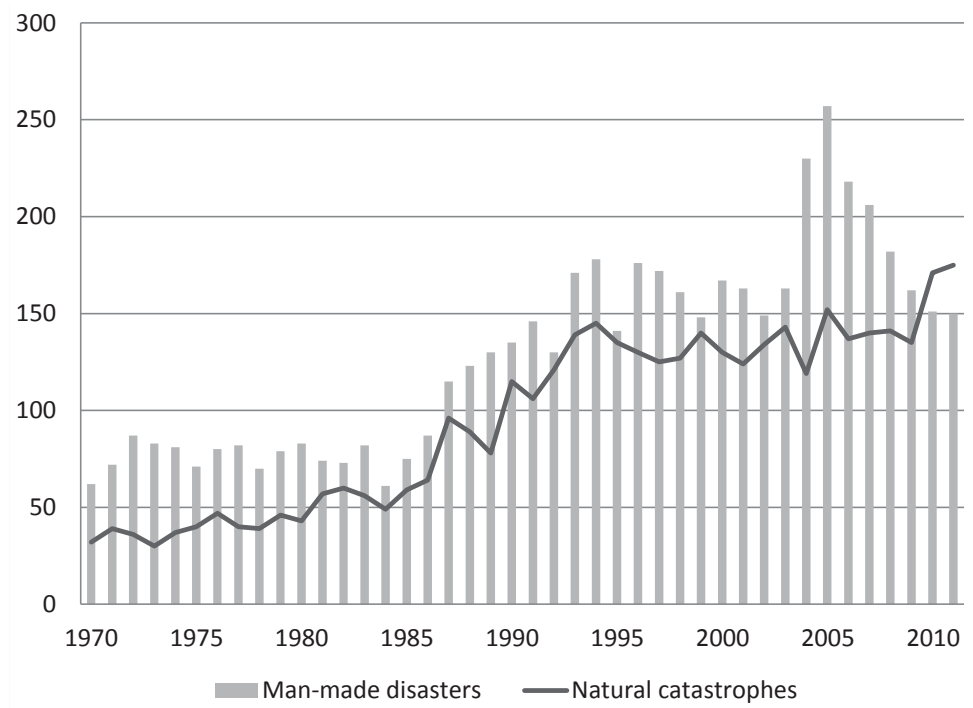


Figure 2.2: Number of Catastrophe Events 1970-2011. Source: Swiss Re (2012).

The development of insured losses induced by natural catastrophes makes apparent that it is challenging for insurance companies to cope with the risk appropriately. Therefore, in Section 2.2, catastrophe risk management is analyzed in general and, in particular, for insurance companies. Important catastrophe risk management instruments for insurance companies to reduce the risk borne are the purchase of traditional reinsurance or the use of alternative risk transfer. Against this background, Section 2.3 deals with the insurance of catastrophe risk. In more detail, the insurance of catastrophe risk is discussed in Section 2.3.1, before the basic mechanisms and shortcomings of traditional reinsurance are presented in Section 2.3.2. Challenges that arise in connection with traditional reinsurance may be solved with instruments of alternative risk transfer. These instruments are presented in Section 2.3.3.

¹³See Table 2.1.



2.2 Catastrophe Risk Management

In the International Graduate College 802 “Risk Management of Natural and Civilization Hazards on Buildings and Infrastructure”, a catastrophe risk management chain has been developed which includes many engineering interdependencies because the process is mainly defined for civil engineering.¹⁴ An overview of the catastrophe risk management chain is presented in Figure 2.3. The risk management chain is very general and consists of three steps, which are risk identification, risk assessment, and risk treatment. In more detail, risk identification refers to an analysis of hazards which may affect the system. The risk assessment is divided into risk analysis and risk evaluation. One part of the risk analysis is the loss assessment including both direct and indirect consequences. These consequences consider economical, humanitarian, CSH (cultural, social, historical), and ecological aspects. Finally, the risk treatment allows for decisions on how the risk shall be treated on the basis of the results of the risk assessment.

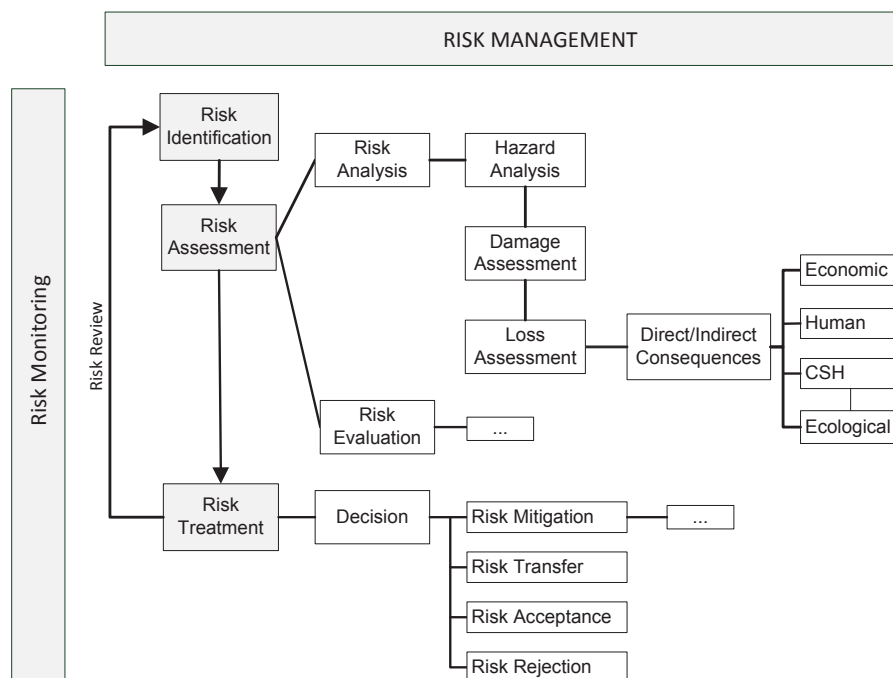


Figure 2.3: Risk Management Chain. Source: Pliefke et al. (2007).

¹⁴Against this background, a basic definition of “structural risk” as well as “total risk” has been provided: Structural Risk = Probability · Damage and Total Risk = Probability · Loss. See Pliefke et al. (2007).



The present work is part of economical consequences which are therefore more specified. In Figure 2.4, an approach for this specification is presented. Considering economic consequences one can discriminate the catastrophe risk into insured and uninsured risk.¹⁵ If a catastrophe occurs that has not been sufficiently insured, usually the government will pay at least part of the loss.¹⁶ In developed countries, usually international aid organizations or international financial institutions like the World Bank are involved in the financing of catastrophe losses.¹⁷ The focus of this thesis is on the consequences of natural catastrophes which have been insured by insurance companies. Large catastrophes may affect the solvency of insurance companies significantly. Therefore, an appropriate risk management is of utter importance for these companies.

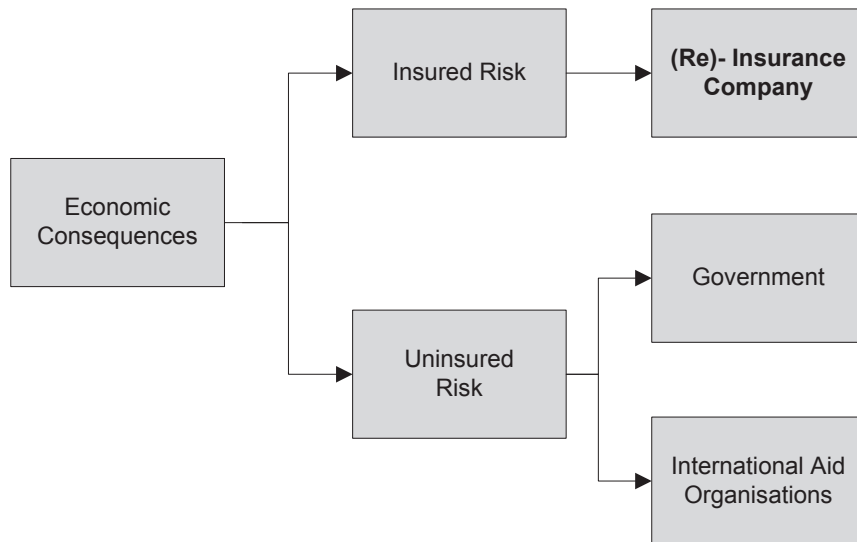


Figure 2.4: Specification of Economic Consequences.

One important purpose of general risk management in insurance companies is to guarantee solvency of a company to a certain extent. As in the above presented

¹⁵See Section 2.3.1 for a detailed discussion on the insurability of catastrophe risk. However, not all uninsured risks are uninsurable from an economic point of view. For instance, people in developing countries are simply not able to pay for insurance.

¹⁶See, for instance, Nichol森 (2004) for information on government programmes for funding of hurricane disasters in Florida. Takeda (2004) describes the role of the government in case of the occurrence of an earthquake. Moss (2004) describes in detail the role of governments for catastrophe risk management. Nell & Richter (2005) analyze to what extent the involvement of governments in catastrophe risk management is reasonable and whether there should be mandatory insurance for certain risks.

¹⁷See Cummins & Mahul (2008). They analyze the financing of catastrophe risks in developing countries. They argue that countries should follow a “proactive disaster risk management approach” instead of only reacting after a catastrophe occurred.



approach, the risk management includes the anticipation and identification of risks, the assessing and modeling of risks as well as the controlling of risks.¹⁸ For an effective risk management in insurance companies, it is necessary that the underwriting units as well as capital and asset management units are involved in the risk management process. The underwriting units identify and assess the risk and derive appropriate prices. The asset units need to ensure that assets and liabilities are balanced. Finally, the capital management needs to ensure that there is no gap between the risk that is assumed and the risk that can be borne in order to ensure solvency.¹⁹

Especially catastrophe risks may affect the solvency of insurance companies significantly due to their above described properties. Thus, catastrophe risk management is of high relevance for these companies. An essential component of catastrophe risk management is the reduction of the risk borne by purchasing reinsurance or instruments of alternative risk transfer. Against this background, the next section deals with the insurance of catastrophe risk.

2.3 Catastrophe Risk Insurance

2.3.1 Insurability of Catastrophe Risk

In the field of insurance of catastrophe events one has to differentiate between *uncertainty* and *risk*. While uncertainty “involves unmeasurable (and perhaps unknowable) probabilities”, risk “involves measurable probabilities.”²⁰ Thus, if one is dealing with uncertainties, no insurance is possible because no occurrence probabilities and expected losses can be determined. When considering risks, usually probabilities can be determined, and risk assessment in terms of mathematical models is possible. Nevertheless, in the literature is a discussion whether there are catastrophe risks that are uninsurable. Jaffee & Russell (1997) define an uninsurable risk as a risk which is too large to be insured, a risk which is not insurable due to adverse selection and moral hazard, or a risk which cannot be calculated by actuarial methods. Nguyen (2007) states that there are no objective limits for the insurability of a risk, since insurance is always a subjective decision problem between insurer and policy holder.

Basically, there are two methods to examine the insurability of risks.²¹ The first approach is an empirical one that explains which risks are insurable by analyzing

¹⁸See Schanz et al. (2010, p. 33).

¹⁹See Baur & Breutel (2004, p. 9 ff.). See Doff (2011, p. 280 ff.) for an extensive overview how risk management processes developed in insurance companies from the 1990s until 2011.

²⁰See Moss (2004, p. 40). He states that in 1920 Frank Knight was the first to distinguish risk and uncertainty in economics.

²¹See Nguyen (2007, p. 85 ff.) and Endres & Schwarze (1992).