1 Introduction

1.1 Problem Definition and Objectives of This Work

According to the 2019 Global Risk Report, extreme weather events and natural catastrophes rank as the first respectively third most relevant global sources of risk in terms of likelihood and as the third respectively fifth in terms of impact (World Economic Forum, 2019). Furthermore, the failure of climate change mitigation and adaption, which are considered even more relevant by the World Economic Forum (2019) in terms of both likelihood and impact, is closely related to the occurrence of natural catastrophes and will probably lead to an increasing frequency and severity of natural catastrophes in the future. The increasing relevance of natural catastrophes is also supported by empirical data: according to Bevere et al. (2019), between 1992 and 2018, the (insured) damages caused by natural catastrophes have increased at an annual rate of 5 (4.7) percent measured by a ten-year moving average. To date, the most devastating year in terms of natural catastrophes has been 2011, the year of the Tohoku earthquake in Japan, when overall economic damages amounted to USD 371 bio. and insured damages to USD 116 bio. (Bevere et al., 2012). From an economic perspective, prevention and mitigation of natural catastrophes is challenging, because they are difficult if not impossible to predict and by definition, their consequences are devastating.

Insurance and reinsurance companies carry out an important function in mitigating the consequences of natural catastrophes. They provide among others insurance for individuals or corporations against catastrophic risks. For many other types of risks, losses

at the individual level exhibit a low level of correlation. Consequently, by making use of diversification effects, insurers are able to cover loss events that would have severe detrimental effects on an individual's or a company's economic situation. In the case of natural catastrophes, losses in the catastrophe region are usually highly correlated at the individual level, which makes it more difficult for an insurance company to cover these risks. Therefore, in order to be able to also cover catastrophic risks, insurance companies transfer parts of these risks to reinsurance companies via reinsurance. Reinsurance companies generally exhibit a higher level of regional diversification compared to insurance companies, which enables them to provide coverage for natural catastrophes more easily. However, the number of participants and size of the reinsurance market are limited. Consequently, the amount of damages incurred by some catastrophic events such as hurricanes Katrina and Sandy in 2005 and 2012, and the Tohoku earthquake in 2011, significantly reduces the capacity supplied by reinsurance markets for subsequent coverage. Therefore, the demand for (re)insurance of catastrophe risk may not be satisfied or may only be satisfied at very high prices (Froot, 2001).

The combination of the increasing frequency and severity of natural catastrophes and the limited capacity of (re)insurance markets creates a challenging market environment for the (re)insurance industry. Therefore, it is not surprising that on a worldwide scale, the majority of catastrophic losses is not covered by (re)insurance.[2] This empirical fact is contrary to risk management theory, which suggests that the protection against catastrophic events is more valuable than other types of insurance coverage (Froot et al., 1993; Froot, 2001).

Given that the theoretical literature assigns a high value to protection against natural catastrophes, it is no surprise that in the 1990's, the limited capacity of the reinsurance market was one of the central causes leading to the invention of catastrophe bonds (CAT bonds) (Froot, 2001). With CAT bonds, insurance and reinsurance companies – which in the case that they issue a CAT bond are referred to as sponsors – can securitize the

[2]The difference between economic losses and insured losses resulting from natural catastrophes is also referred to as the protection gap (Bevere et al., 2012, 2019). As can be seen from the above-mentioned economic and insured damages in 2011, the year of the Tohoku earthquake, the protection gap amounted to approximately USD 255 bio.

insured catastrophic risk and transfer it to the capital markets. As the capital market exhibits a significantly larger capacity than the reinsurance market, CAT bonds may provide a valuable remedy to the above-mentioned capacity problems of the (re)insurance market. In fact, since the inception of the CAT bond market in the 1990's, the outstanding risk capital has shown a significant growth from USD 786 mio. in 1997 to USD 42,367 mio. in 2020 (Artemis, 2019). With the growing utilization of CAT bonds, the scientific literature gained a better understanding of the market and was able to establish accurate pricing models to predict CAT bond premiums[3] (Galeotti et al., 2013; Braun, 2016; Gürtler et al., 2016). However, whereas comprehensive empirical evidence exists on the pricing of CAT bonds, it is widely unstudied how successfully that market satisfies the demand for catastrophe risk transfer. In this context, three aspects are of particular interest. First, no empirical evidence exists with regard to the joint use of CAT bonds and traditional risk transfer via reinsurance. Thus, it is unclear if CAT bonds provide added value to (re)insurers' risk management strategies and if (re)insurers therefore substitute traditional reinsurance by CAT bonds. Second, the access of (re)insurers to the CAT bond market has not been studied comprehensively. More specifically, given that CAT bonds are issued on the capital market, it is likely that the CAT bond market exhibits information inefficiencies that create demand side barriers to entry for sponsors / (re)insurance companies. Third, in order to assess the success of CAT bonds from a supply side perspective, it is questionable if moral hazard, which occurs on traditional (re)insurance markets, is also relevant on the CAT bond market.

Against this background the present thesis raises three important research questions:

- Do CAT bonds add value to (re)insurers' risk management and are CAT bonds therefore used as substitutes for traditional reinsurance? Which factors influence the substitution of reinsurance by CAT bonds?
- Is the CAT bond market equally accessible for different (re)insurers? Does the premium of CAT bonds depend on sponsor-specific factors, that means, on the characteristics of the CAT bond-sponsoring (re)insurers? Does the before-mentioned

[3]The premium is the component of a CAT bond's coupon that is paid above a risk-free interest rate.

dependency signal the existence of information inefficiencies?

- Are (re)insurance companies that sponsor CAT bonds susceptible to moral hazard?

An analysis of the above research questions is valuable, because it improves the understanding of the CAT bond market and of the challenges related with catastrophe risk management. This thesis studies the three above research questions on the basis of empirical analyses. In the first empirical analysis, substitution effects between CAT bonds and traditional reinsurance and their determinants are examined to investigate if CAT bonds provide added value to (re)insurers' risk management strategies. The second empirical analysis is dedicated to measuring the influence of company-specific variables on CAT bond premiums to test the presence of information inefficiencies in the CAT bond market. The third empirical analysis introduces an approach to identify and measure the presence of moral hazard in the CAT bond market.

1.2 Course of Investigation

In order to analyze the research questions mentioned above, the thesis proceeds as follows.

Chapter 2 establishes a basic understanding of the structure of CAT bonds. Furthermore, a brief overview on the development of the CAT bond market and its properties is given.

Chapter 3 analyzes the joint use of CAT bonds and reinsurance to answer the question whether and in dependence of which factors CAT bonds are used as substitutes for reinsurance. Section 3.1 and describes the motivation of the analysis. Section 3.2 reviews the relevant literature and derives the hypotheses to be tested in the empirical analysis. Section 3.3 reviews the data set employed in the empirical analysis by describing the sample selection and the used set of variables and presenting descriptive statistics. The empirical analysis is conducted in Section 3.4. The existence of substitution effects is first analyzed with a baseline model. Afterwards, the different hypotheses are tested in suitable model frameworks. Finally, the robustness of the results is tested. The interim

results of this chapter are summarized in Section 3.5.

Chapter 4 studies the accessibility and efficiency of the CAT bond market by an analysis of the relationship between CAT bond premiums and sponsor-specific factors. In Section 4.1, an overview of the relevant literature and the motivation for the analysis are presented. In Section 4.2, five hypotheses concerning the influence of sponsor characteristics on the premiums of CAT bonds are introduced. Section 4.3 gives an overview of the data set employed in the empirical analysis and consists of the sample selection, the description of the used variables, and the descriptive statistics. The empirical analysis is part of Section 4.4. Before discussing the empirical results, the model framework and the approach to model seasonalities of CAT bond premiums are described. Afterwards, an analysis of sponsor-specific variables in the overall sample and in the subsample of non-indemnity CAT bonds and a heterogeneity test are conducted. The interim results of this chapter are summarized in Section 4.5.

Chapter 5 examines if CAT bond sponsoring (re)insurers are susceptible to moral hazard. First, the relevant literature and the motivation of the empirical analysis are presented in Section 5.1. In Section 5.2, a measure for moral hazard and the hypotheses to be analyzed in this chapter are derived. Section 5.3 gives an overview of the data set employed in the empirical analysis by describing the sample selection and the variables and presenting descriptive statistics. The results of the empirical analysis are presented and discussed in Section 5.4. This section contains the results obtained with a benchmark model, an analysis of the effect of loss retention, a subsample analysis for CAT bond sponsors, and a series of robustness checks. Section 5.5 subsumes the results obtained in this chapter.

Chapter 6 concludes this thesis.

2 Structure and Market of CAT Bonds

2.1 The Structure of CAT Bonds

A CAT bond transaction is based on a reinsurance agreement between a sponsor – typically an insurance or reinsurance company – and a special-purpose vehicle (SPV). The structure of such a transaction is depicted in Figure 2.1. The SPV issues securities (the actual bonds) to fund the risk incurred by the reinsurance agreement. For receiving insurance coverage from the SPV, the sponsor pays a premium (1). The securities issued by the SPV are purchased by investors, who provide a limit, which is also referred to as principal (2). The principal provided by investors is used to purchase highly rated collateral, which is then held in a trust account (3). The collateral investment generates regular interest rate payments, which are passed to the investors (4, 5).[4] In addition, the investors receive a substantial share of the premium paid by the sponsor (5). Consequently, the investors' coupon consists of a risk-free rate from the collateral investment and a risk premium. The reinsurance agreement between the sponsor and the SPV contains a trigger mechanism used to define the occurrence of a catastrophic event. If no catastrophe event occurs during the life of the bond, then the investors receive the full capital resulting from collateral liquidation when the CAT bond matures (5). At the

[4]Before the financial crisis, CAT bonds frequently entailed a total return swap (TRS), in which the swap counterparty provided a floating rate in exchange for the fixed coupons from the collateral investment in order to minimize interest rate risk and provide investors with a floating rate such as LIBOR. However, four CAT bonds defaulted on interest payments due to the default of the investment bank Lehman Brothers, who was a swap counterparty in these four transactions. Afterwards, the TRS was no longer used in CAT bonds and the interest rate risk was instead minimized through collateral investment in money market funds on a rolling short-term basis (Cummins & Weiss, 2009; Braun, 2016).

occurrence of a catastrophic event under the reinsurance contract, the collateral is liquidated, the sponsor is indemnified for his losses, and the investors loose (part of) their principal (6). The catastrophe risk entailed in a particular CAT bond is modeled by specialized third-party risk modeling companies, which provide investors with an estimate for the bond's financial loss distribution.[5] The most popular parameter to reflect the loss distribution is the expected loss (EL), and empirical studies that analyze the risk premiums of CAT bonds consistently show that the EL has a significantly positive influence on premiums (Major & Kreps, 2003; Dieckmann, 2008; Lane & Mahul, 2008; Bodoff & Gan, 2009; Papachristou, 2011; Braun, 2016; Gürtler et al., 2016).[6]

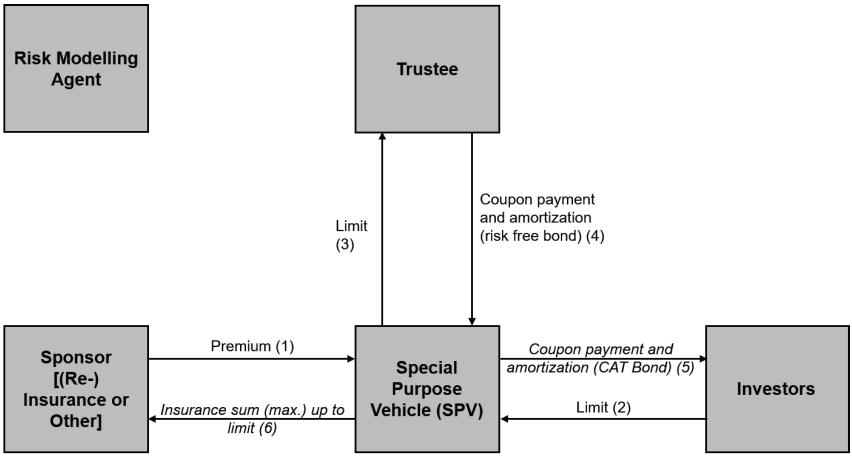

Figure 2.1: CAT Bond Structure.

[5]This description of the structure of CAT bonds is based on Cummins & Weiss (2009), Galeotti et al. (2013), Braun (2016), and Gürtler et al. (2016).

[6]Alternative parameters for describing the loss distribution include the probability of first loss (PFL), conditional expected loss (CEL), and the probability of last loss, which is the probability of losses suffered by the CAT bond equal to or greater than the limit (Lane, 2000; Wang, 2000, 2004; Dieckmann, 2008).

2.2 Development and Properties of the CAT Bond Market

The CAT bond market was created in the 1990s.[7] Figure 2.2 exhibits the development of outstanding risk capital in the CAT bond market and altogether shows a strong growth tendency. Two periods in this graph stick out. Between 2005 and 2007, the outstanding capital increased sharply, which was mainly caused by the damages resulting from the 2005 U.S. hurricane season (including hurricanes Katrina and Rita) that had severely depleted reinsurance capital. After 2008, CAT bond capital decreased in consequence of the financial crisis, which led to the default of four CAT bonds on interest payments (see also Section 2.1) and reduced the trust of investors in CAT bonds and structured financial products in general. From 2011 on, however, the CAT bond market experienced a steady and significant growth.

Figure 2.2 also exhibits the development of net reinsurance premiums written by the 40 largest reinsurers in the world, which can be considered as a measure of the global reinsurance market's capacity. Although its growth does not parallel the growth of the CAT bond market, it is observable that the reinsurance market also grew considerably during the period under consideration. One can further observe that the devastating hurricane season 2005 entailed an increase of reinsurance premiums. However, that increase was less pronounced than the capital increase on the CAT bond market, which suggests that reinsurance market capacity is somehow constrained in the short and medium term. A third stylized fact that results from Figure 2.2 is observable during the period after the financial crisis. In contrast to CAT bond volumes, which stagnated at their 2009 levels until 2011, reinsurance premiums already started to increase again in 2009. This implies that the CAT bond market is more strongly dependent on global financial markets compared to the traditional reinsurance market.

[7] According to the literature, diverging opinions exist in terms of the actual first CAT bond transaction (Tilley, 1998; Mocklow et al., 2002; Schöchlin, 2002; Cummins & Weiss, 2009; Artemis, 2020). However, reproduced deals can be observed since 1997 so that this can be considered the year of market inception (Mocklow et al., 2002).

Figure 2.2 does not allow a valid conclusion in terms of the first research question that is related to the added value of CAT bonds and the existence of substitution effects between CAT bonds and reinsurance. Over the past two decades, both risk management instruments exhibit a growing utilization. From a macroeconomic perspective, CAT bonds and reinsurance may show different degrees of dependency on the global financial markets and different potentials for short-term capacity increases. However, the added value of CAT bonds compared to traditional reinsurance and the existence of a substitution effect can only be examined at the individual company level, which is the subject of Chapter 3.

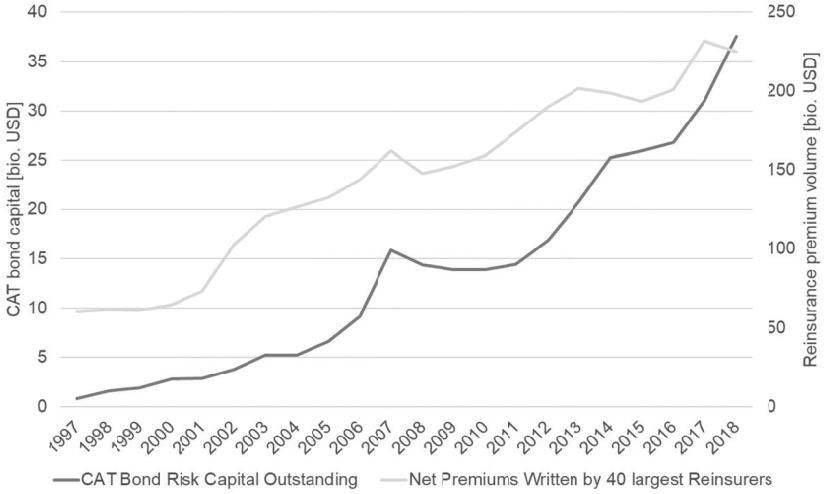

Figure 2.2: Development of Reinsurance and CAT Bond Markets, 1997-2018. Source: Artemis Deal Directory and Standard & Poor's Global Reinsurance Market Highlights 2005-2018.
From 1997 to 2001, pure life insurers are excluded from the set of companies, which explains the jump in net reinsurance premium volume from 2001 to 2002. Due to lack of data, the reinsurance premium volume in 2004 has been interpolated.

Table 2.1 ranks the five most active CAT bond sponsors in terms of their aggregate issue volume over the period from 1997 to 2018. The companies listed in this table exhibit

several common characteristics. They are all either insurance or reinsurance companies, which confirms that CAT bonds are predominately used by the insurance industry.[8] The magnitude of the net premium volume and the companies' total assets indicate that they are among the largest market participants in their respective industries. In fact, the three reinsurers in Table 2.1 are the three largest reinsurers worldwide based on their current premium income. The two insurance companies State Farm and USAA are the first respectively the eighth largest writer of property and casualty insurance in the USA (Insurance Information Institute, 2020). The rating exhibited in the last column further shows that all of the most active sponsors exhibit a very high credit quality (Standard & Poor's, 2019). Table 2.1 indicates that the CAT bond market is dominated by large companies with a relatively high credit quality. This dominance is obviously due to the fact that larger companies have a higher demand for risk transfer. Nevertheless, Table 2.1 also raises the question if access to the CAT bond market is more difficult for smaller companies or companies with a lower credit quality. This assumption is also supported by the relatively small number of sponsors that issued a CAT bond with a lower quality credit rating. Based on the data set used in this thesis that comprises most of the transactions conducted since the inception of the CAT bond market, only four sponsors issued a CAT bond at a time when their credit rating was not in the investment grade segment:[9] the Turkish Catastrophe Insurance Pool of the Turkish government, the Italian insurers Generali and UnipolSai, and the Bermudian reinsurer Montpelier Re. This anecdotal evidence that suggest sponsors with a higher credit quality are more active on the CAT bond market does not result trivially from theory. As described in Section 2.1, CAT bonds are issued via an SPV, which isolates the covered risks from the sponsor's general business risk (Smack, 2016). Thus, it is not intuitive that sponsors with a higher credit quality are more successful on the CAT bond market, because investors should be indifferent toward sponsor-related risks that are not

[8] The most active non-(re)insurance sponsor in the CAT bond sphere is the International Bank for Reconstruction and Development that until March 2018 had sponsored a series of CAT bonds amounting to a total volume of USD 1,720 mio. in cooperation with the governments of some Central and Latin American countries to insure hurricane and earthquake risks in those countries.

[9] For Standard & Poor's, ratings are considered as investment grade if they are BBB- or better and speculative grade below BBB- (Standard & Poor's, 2016). The definitions of other rating agencies are analogous (Fitch, 2017; Moody's, 2016).