

Gürtler, M.; Hibbeln, M.; Winkelvos, C.

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The Impact of the Financial Crisis and Natural Catastrophes on CAT Bonds

Marc Gürtler Martin Hibbeln Christine Winkelvos *

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CAT bonds are important instruments for the insurance of catastrophe risk. Due to a low degree of deal standardization, there is uncertainty about the determination of the CAT bond premium. In addition, it is not apparent how CAT bonds react after the financial crisis or a natural catastrophe. We empirically verify which factors determine the CAT bond premium and what effects arise if a catastrophe occurs. On a broad data set using secondary market premiums we find strong evidence that the recent financial crisis has a significant impact on CAT bond premiums. Furthermore, we find that after hurricane Katrina an increased risk perception for hurricanes can be observed.

JEL classification: G01, G22

Keywords: CAT Bonds, Financial Crisis, Catastrophe Events, Risk Premium

*All authors: Braunschweig Institute of Technology, Department of Finance. Prof. Dr. Marc Gürtler, marc.guertler@tu-bs.de. Dr. Martin Hibbeln, martin.hibbeln@tu-bs.de. Dipl.-Math. Oec Christine Winkelvos, c.winkelvos@tu-bs.de.

1 Introduction

Increasing insured losses that have been induced by severe natural catastrophes during the last decades brought up the problem that traditional reinsurance has not been sufficient due to capacity shortage. Several alternative instruments came up to give remedy to capacity shortage on reinsurance markets (Cummins and Weiss (2009)). CAT bonds are of particular importance among these instruments. They secure natural catastrophes by reducing coupon or principal payments when a certain natural catastrophe occurs in a certain region. In 2011 the amount of total risk capital of CAT bonds was USD 11.89 billion (Carpenter (2012)). It is assumed that the CAT bond market will continue to grow in the future (Cummins and Weiss (2009)). An important condition for successful trading of securities is the determination of accurate prices. However, because CAT bonds are not standardized, it is a challenging question how to price CAT bonds accurately. There can be various factors that influence the risk premium that is required by investors. For instance, it is usually assumed that the chosen trigger mechanism or the peril affect the CAT bond premium. However, in the literature there are only few empirical studies that analyze on relatively small data sets which factors determine the CAT bond premium. Moreover, it is widely unknown how CAT bond premiums react to natural catastrophes and particularly to financial crises. Against this background, we analyze the reaction of CAT bond premiums after such events. Moreover, we examine which factors influence CAT bond premiums.

The occurrence of a catastrophe is measured by a trigger mechanism that defines the default of the bond. The sponsor who wants to insure against specific catastrophe losses typically does not issue the CAT bond itself but uses a special purpose vehicle (SPV) as an intermediary. The SPV acts as a kind of insurer for the sponsor and issues CAT bonds to investors. The sponsor needs to pay premiums to the SPV. Expressed in simplified terms, the SPV pays these premiums above LIBOR to investors as part of coupon payments. The premium consists of the expected loss (EL) and a risk premium and can be modeled by premium calculation principles.

There exist several modeling approaches for CAT bond premiums in the literature, namely linear models, loglinear models and the Wang transformation model (Lane and Mahul (2008); Major and Kreps (2003); Wang (2000)). There is evidence that the linear model is an appropriate approach to describe and to predict CAT bond premiums (Galeotti et al. (2012)). Subsequently, we present a brief review of empirical findings regarding CAT bond premiums. Berge (2005) analyzes a linear approach and identifies, for instance, the number of perils as a significant premium determining factor. He analyzed CAT bond issue data from 1994 to 2004. Lane and Mahul (2008) use issue data as well as secondary market data of CAT bonds in order to establish cross-sectional analyses at different points in time. They find that the risk premium is higher for Wind perils in the United States than for other peril types. Dieckmann (2011) analyzes secondary market data in the surrounding field of hurricane Katrina. Therefore, he analyzes 61 CAT bonds with observations between 3/31/2005 and 03/31/2006. He identifies, for instance, the applied trigger mechanism as a premium determining factor. Furthermore, he finds that premiums were significantly higher after hurricane Katrina than before. Finally, Galeotti et al. (2012) find that (a multiple of) EL is sufficient in order to forecast the CAT bond premiums at issue by analyzing a data set of CAT bonds issued between 1999 and 2009. They could not identify that including CAT bond specific variables leads to improvements of out-of-sample results.

Even if there already exist some empirical analyses on CAT bond premiums, there are a few drawbacks. First, several empirical findings stay in conflict with each other. For instance, Berge (2005) does not find any significant influence of the applied trigger mechanism on the CAT bond premium, whereas Dieckmann (2011) finds that CAT bonds using an indemnity trigger are imposed by investors with a higher risk premium than non-indemnity triggered CAT bonds. The reason could be that the empirical analyses are largely based on rather small samples. Thus, additional analyses on larger data sets are important. Second, there is little knowledge about the impact of natural catastrophes on CAT bond premiums. Third, to the best of our knowledge, there is no empirical analysis

about the impact of financial crises on CAT bond premiums. The reaction of premiums on natural catastrophes and financial crises is important for investors for the following reason. While the motivation for the sponsor of issuing a CAT bond lies in catastrophe risk insurance, it is often stated that it is advantageous for investors to buy CAT bonds due to diversification effects. These result from low correlations to other securities that are traded on capital markets. The events of hurricane Katrina and the recent financial crisis questioned this assumption. It is widely agreed in the literature that if a natural mega-catastrophe occurs, both the CAT bond market and the capital markets are affected and correlation develops (Cummins and Weiss (2009)). However, it is not apparent how the CAT bond market reacts concretely. There could be an increase of premiums for all types of perils due to a generally increased risk aversion of market participants or there might be an increase of premiums that insure against perils of the same type as the occurred catastrophe. For the case of financial crises, the dependency between the event and the CAT bond market is not apparent. Two situations are possible. The CAT bond market might be independent of capital market developments even if a financial crisis occurs, or a financial crisis could affect not only the capital markets but also the CAT bonds market, e.g. due to a general increased risk aversion of market participants.

Against this background, our main research questions are:

- Which factors determine the premium of a CAT bond?
- How do natural catastrophes or financial crises influence the CAT bond premium?

We analyze these research questions using a data set of secondary market CAT bond premiums from 2002 to 2012. This is virtually the whole data set that is available for secondary market CAT bond premiums. Considering CAT bond specific information, we find that there is no significant influence of the applied trigger mechanism on the premium. This is in contrast to the widespread expectation in the literature, but it can be explained by a special payment structure included in most indemnity triggered CAT bonds. Thereby, both sponsor and investor share the risk proportionally above the trigger level. Addressing perils, we find that if the number of insured peril regions or peril types

increases, also the premium increases due to higher deal complexity. Furthermore, we find that if the rating declines, the CAT bond premium increases. Thus, investors use rating information for their investment decision. Finally, we cannot find any empirical evidence for a liquidity premium measured by maturity and volume of the CAT bond.

Analyzing macroeconomic factors, catastrophe events, and the financial crisis, we find that there is a significantly positive dependency between the development of reinsurance premiums and CAT bond premiums. This can be explained by market imperfections and by the fact that CAT bonds are an alternative to traditional reinsurance. In addition, we verify that there is a dependency between capital markets and the CAT bond market measured by means of credit spreads of corporate bonds. We find that this dependency grows significantly in the course of the financial crisis. Thus, we can conclude that the financial crisis has an important influence on CAT bond premiums. Finally, we find that a natural mega-catastrophe such as hurricane Katrina results in higher premiums for hurricane perils only. Thus, market participants do not react to hurricane Katrina with a general distrust in the reported expected losses. Instead, the risk perception for hurricanes rises.

This study makes the following contributions: First, to the best of our knowledge, this is the first empirical study that analyzes the impact of the financial crisis on CAT bond premiums. Second, we provide new insights into the reaction of investors after natural catastrophes. Third, our results improve the understanding which factors influence the premiums of CAT bonds.

The procedure of the paper is as follows. The research hypotheses are derived in Section 2, where we consider CAT bond specific hypotheses as well as macroeconomic and event hypotheses. In Section 3 the data set for the empirical analysis is presented. We present and discuss the results of our empirical analysis in Section 4. Finally, Section 5 concludes.

2 Hypotheses

In the literature, there is a discussion about the factors that determine the CAT bond premium. In the following, we describe CAT bond specific factors that are possible determining factors of the CAT bond premium. Subsequently, we discuss the possible influence of macroeconomic factors and catastrophe events. In the course of the discussion, we derive several hypotheses on premium determining factors and on the reaction of CAT bond premiums on catastrophe events.

2.1 CAT Bond Specific Hypotheses

Typically, the default of a CAT bond is measured by a trigger mechanism. Trigger mechanisms can be separated into indemnity triggers and non-indemnity triggers. Non-indemnity triggers can further be divided into parametric (index) triggers, industry index triggers, modeled loss triggers and hybrid triggers.¹ Indemnity triggers depend on the actual losses of the sponsor which implies that no basis risk for the sponsor results but the investors are opposed to information asymmetries in terms of moral hazard. This can be reduced or eliminated if non-indemnity triggers are applied. However, in this case there occurs basis risk for the sponsor (Cummins et al. (2004)). Analyzing the trade off between basis risk and moral hazard, it is argued in the literature that CAT bonds with indemnity triggers have higher premiums and are less traded compared to CAT bonds with non-indemnity trigger mechanisms (Cummins and Weiss (2009); Doherty (2000); Dubinsky and Laster (2003)). On a relatively small data set, Dieckmann (2011) finds empirical evidence for the assumption that indemnity triggered CAT bonds are imposed with an additional premium. In contrast, Berge (2005) does not identify a significant influence of the applied trigger mechanism. In addition, Carpenter (2007) states that several disadvantages for both sponsor and investor are associated with the indemnity trigger. The rating process takes longer compared to other trigger mechanisms,

¹We refer to Cummins and Weiss (2009) and Galeotti et al. (2012) for further information on the non-indemnity trigger mechanisms.

and a more detailed risk analysis is necessary resulting in a longer preparation phase than when applying a non-indemnity trigger. However, market developments show that the indemnity trigger has regained importance in the last years. Cummins and Weiss (2009) assume that this development is due to a special payment structure included in the CAT bond contract. Here, both sponsor and investor share the risk proportionally above the trigger level. This is referred to as incentive provisions. However, Cummins (2008) points out that even if this structure is chosen, the problem of moral hazard remains. In compliance with the literature we expect the *trigger hypothesis*.

Trigger hypothesis (H1): CAT bonds with indemnity trigger are imposed by investors with higher risk premiums than CAT bonds with non-indemnity triggers.

The peril can be distinguished with regard to the peril type and with regard to the number of securitized perils which can be only one peril or multiple perils. Apparently, this can be done also for the region of the peril. Banks (2004) finds that the number of multiple peril bonds is increasing. Carpenter (2007) states that especially sponsors like to insure as many peril types as possible by one CAT bond due to reduced transaction costs and the sharing of limits for several risk regions. Instead, investors tend to prefer single peril CAT bonds. That enables them to buy the CAT bond which fits best to their investment strategy. Berge (2005) finds empirical evidence that the premium of the CAT bond declines if only one risk type is insured. Summarizing, we assume the *complexity hypothesis*.

Complexity hypothesis (H2): An increasing number of peril types or peril regions is opposed by investors with higher risk premiums.

The catastrophe risk that arises when securitizing different perils is examined by specialized firms. After the catastrophe risk has been determined, the rating process starts. Because CAT bonds are fully collateralized, the rating is mainly done by analyzing the probability that a triggering event will occur (Cummins (2008)). Therefore, the rating agencies basically rely on the catastrophe risk assessment as established by risk modeling firms because the rating agencies are not originally specialized in catastrophe risk assessment. However, it is questionable whether a rating process is independent and reliable

if it is based on provided risk models (Anders (2005)). Krutov (2010) even states that investors in general do not rely on CAT bond ratings. Despite all points of criticism, the rating agencies provide easily accessible information for investors and might improve the investment decision process. If investors use the rating for their investment decision, a lower CAT bond rating should be connected with higher risk premiums. Thus, we assume the *rating hypothesis*.

Rating hypothesis (H3): Investors demand higher risk premiums for CAT bonds with lower ratings.

Following Dieckmann (2011) and Berge (2005), we measure liquidity in terms of maturity and volume. If investors demanded an additional premium for investing in an illiquid market, the maturity would be positively connected with the CAT bond premium, whereas the volume would be negatively connected (Dieckmann (2011)). For the CAT bond market, neither Dieckmann (2011) nor Berge (2005) could identify any influence of maturity or volume on CAT bond premiums. However, they only analyzed a short period of observations on the CAT market. Because these empirical findings are not in line with theoretical predictions, we consider the following liquidity hypotheses.

Liquidity hypotheses:

(H4a): Investors demand a liquidity premium for longer maturity and for lower volume of the CAT bond.

(H4b): Investors do not demand a liquidity premium for CAT bonds.

2.2 Macroeconomic and Event Hypotheses

It is often stated in the literature that CAT bonds are attractive for investors because they are – if at all – lowly correlated with other asset classes. For instance, Litzenberger et al. (1996) find that catastrophes are lowly correlated with security market returns. Thus, instruments with a catastrophe related payment structure are suitable for diversification for investors. Furthermore, Galeotti et al. (2012) could not identify any correlation between financial markets and the CAT bond market, although it has to be stated that

they analyzed only issue data. In contrast, Dieckmann (2011) shows correlation coefficients between 2002 and 2011 for several capital market variables and CAT bond returns. He finds that there is a high correlation between different bond indexes and CAT bond returns.

However, if there is a correlation between capital markets and CAT bond markets, this could be motivated by two directions. First, a CAT bond market change due to a natural catastrophe such as hurricane Katrina could as well influence capital markets if the overall economy is affected by the event. Second, a devastating event on capital markets such as the financial crisis could as well affect prices for CAT bonds, e.g. due to an increased risk aversion of market participants. In the following, we in-depth analyze both approaches resulting in the *natural catastrophe hypothesis* and the *financial crisis hypothesis*.

In general, there is empirical evidence that catastrophes do have an impact on capital markets. For instance, Worthington and Valadkhani (2004) identify an influence of catastrophe events on the Australian capital market by analyzing daily returns of the All Ordinaries Index. They find evidence that the capital market is especially affected by cyclones, earthquakes and bushfires. For the special case of CAT bonds, Cummins (2008) states that the assumption of independence between capital markets and the CAT bond market only holds in normal market situations. If a natural mega-catastrophe such as hurricane Katrina occurs, both the CAT bond market and the capital markets are affected. He suggests that under consideration of huge natural catastrophe events, there might be a correlation between capital markets and the CAT bond market due to lower prices for securities on capital markets and higher premiums for CAT bonds. In addition, Krutov (2010) states that the “zero-beta” assumption was first questioned after hurricane Katrina and could become completely invalid after another mega-catastrophe such as an earthquake in California.

In the past, particularly hurricanes caused severe losses to insurance companies. Hurricane Katrina in 2005 caused USD 62.2 million insured losses which are the highest single event losses to the insurance industry since records are available. The third largest

catastrophe since 1980 was hurricane Ike in 2008 with USD 18.5 million insured losses.² In addition, simulation studies predict that even more severe hurricanes might occur in the future due to climate change and related problems (Banks (2004)). Lane and Mahul (2008) find that wind perils in the United States – which include hurricanes – are imposed by the market with higher risk premiums than other perils. Cummins and Weiss (2009) state that premiums and expected losses rose significantly after hurricane Katrina. However, it is not apparent whether increasing premiums have been observed on the whole CAT bond market or only CAT bonds that insure hurricane perils have been imposed with higher premiums by the market. Thus, although the expected loss should reflect the risk appropriately and although the risk assessment has been adjusted after hurricane Katrina, especially for hurricane perils investors tend to doubt the accurate modeling of risks.

The situation concerning earthquakes is somehow different. Although earthquakes cause severe losses for the overall economy, they are less insured than hurricane perils. However, Munich Re (2012) states that earthquake perils will be more insured and securitized after the devastating Tohoku earthquake in 2011. Furthermore, the market awaits new results on earthquake risk modeling (Carpenter (2012)). Because our data set does not consider the effects of the Tohoku earthquake sufficiently, we do not analyze this effect.

Summarizing, we assume that there is a correlation between the CAT bond market and capital markets in case of mega-catastrophes. However, it is not obvious how the CAT bond market reacts after such a catastrophe. Altogether, we assume the following *natural catastrophe hypothesis* for the case of hurricanes.

Natural catastrophe hypothesis (H5): Premiums of CAT bonds that insure hurricane perils increase after a mega-hurricane occurred.

We do not only analyze the occurrence of natural mega-catastrophes but also of the recent financial crisis triggered by the bankruptcy of Lehman Brothers. Krutov (2010) suppose that there were high correlations between capital markets and the CAT bond market in the course of the financial crisis. Lane and Beckwith (2009) measure the

²The information is provided by NatCatSERVICE of Munich Re in 2012.

correlation between returns of insurance-linked securities and the index S&P 500. They find that the correlation was very low before mid 2008 and rose to over 30 percent by the end of 2008. However, Cummins and Weiss (2009) find that CAT bonds performed better during the financial crisis than comparable corporate bonds. They conclude that CAT bonds seem to be largely independent of other securities on capital markets. However, it seems plausible to assume that the flight to quality that can be observed in financial crises also affects the CAT bond market and leads to increased risk premiums. Altogether, we formulate the *financial crisis hypothesis*.

Financial crisis hypothesis (H6): If a financial crisis occurs, the positive dependency between corporate credit spreads and CAT bond premiums increases.

Usually, CAT bonds have longer maturities than traditional reinsurance. While CAT bonds have an average maturity of about three years, reinsurance contracts last about one year. Therefore, the sponsor of a CAT bond is protected against cyclical behavior of the reinsurance market (Cummins (2008)). Furthermore, traditional reinsurance markets are affected by capacity shortage after a catastrophe which drives prices (Froot (2001)). For instance, after hurricane Katrina occurred, the traditional reinsurance market tightened due to capacity shortage, and prices rose. Although the CAT bond market is not affected by these market imperfections, it showed the same behavior. Cummins and Weiss (2009) find two reasons for this development. First, the risk assessment of CAT bonds is questioned after a mega-catastrophe. Second, expertise is required to participate on the CAT bond market. Thus, if the demand for CAT bonds shifts after a catastrophe, new market participants need to build expertise before participating on the CAT bond market. Consequently, the premiums increase due to “shortage of expertise” instead of “shortage of capital” on the traditional reinsurance market (Cummins and Weiss (2009)). In addition, CAT bonds can be regarded as an alternative to traditional reinsurance (Finken and Laux (2009)). This would imply that the premiums on both markets should behave similarly. Against this background, we formulate our *reinsurance hypothesis*.

Reinsurance hypothesis (H7): There exists a positive influence of traditional reinsurance premiums on CAT bond premiums.

3 Data

3.1 Sample Selection

The initial data set consists of 387 CAT bond transactions issued between December 1997 and March 2012 which secure natural catastrophe perils. This data set represents virtually the whole universe of CAT bonds that are traded on secondary markets. For the secondary market prices, we use data provided by Lane Financial LLC. This data starts in the second quarter of 2002 and is determined as averaged quotes of several dealers. In the beginning of the period the dealers were Aon, Cochran Caronia, Goldman Sachs and Lehman (Lane and Beckwith (2003)). Over time, the dealers who provided secondary market quotes changed slightly (Lane and Beckwith (2006, 2009, 2010)). For the published averaged market indications, bid-ask spreads are averaged and these averaged spreads are averaged again for all dealers. The information on the applied trigger mechanisms and perils has been collected from Aon Benfield Securities, S&P and the online portal ARTEMIS.

From the original data set, several CAT bonds are eliminated. First, we removed several transactions for which the expected loss, the peril type or the rating is missing because we assume these factors to be essential components of the CAT bond premium. Second, we eliminated transactions that have been labeled *lehman* or *distressed* by Lane Financial LLC. There are four CAT bonds that have been labeled *lehman*. These bonds defaulted following the bankruptcy of Lehman Brothers because Lehman Brothers Special Financing was the total return swap counterparty. The CAT bonds that have been labeled *distressed* were somehow affected by a triggering event like hurricane Katrina in 2005 or the Tohoku earthquake in 2011.³ Third, concerning the peril type, we exclude transactions that insure floods, hails, tornadoes, industry losses or multiple perils because there exist only few transactions that insure these perils. Fourth, we exclude CAT bonds if the

³In the literature, there is no exact definition of the term *distressed CAT bond*. A private conversation with Roger Beckwith (Vice President and Secretary of Lane Financial LLC) revealed that, generally speaking, distressed CAT bonds are issues for which a possible triggering event has occurred. Prices for these bonds can be depressed just on the possibility of loss. Once loss estimates are released that approach or exceed the trigger level, prices will begin to firm at the estimated level of loss. Actually, getting to the real loss can be a lengthy process depending on the type of trigger.

data is implausible, for instance, because the expected loss does not equal the product of probability of first loss and the conditional expected loss.

When examining secondary market premiums for CAT bonds, apparently the problem of seasonality arises for all peril types except earthquakes. We outline this problem for hurricanes. During the hurricane season, the secondary market premiums increase due to a higher probability of a triggering event compared to non-hurricane seasons. In addition, if a CAT bond that securitizes hurricanes matures after the hurricane season, obviously the premiums will decline heavily in the preceding quarters. In order to avoid such seasonal fluctuations, we eliminate secondary market premiums for perils other than earthquake if the remaining time to maturity deviates from a multiple of a full year. The remaining data set consists of 252 CAT bond transactions with 1119 observations.

3.2 Variables

3.2.1 CAT Bond Specific Variables

An essential component of the CAT bond premium is the *expected loss* (EL). The EL results from the risk analysis by specialized firms as Applied Insurance Research Worldwide (AIR), Risk Management Solutions, Inc. (RMS), and Eqecat, Inc. (EQECAT). It consists of the probability of first loss (PFL) for the CAT bond and the conditional expected loss (CEL) by means of $EL = PFL \cdot CEL$. In insurance economics, the EL of a non-negative random loss variable can be interpreted as a lower bound for the premium in order to avoid insolvency of the insurance company. Thus, it is an important parameter of the CAT bond premium.

In order to measure the influence of *trigger mechanisms* on the CAT bond premium, we build the dummy variable “Trigger Indemnity”, that is defined as follows:

$$\text{Trigger Indemnity} = \begin{cases} 1, & \text{if an indemnity trigger is applied,} \\ 0, & \text{if a non-indemnity trigger is applied.} \end{cases} \quad (1)$$

The non-indemnity trigger consists of the parametric trigger with about 47 percent, the industry index trigger with about 33 percent, the hybrid trigger with about 12 percent, and the modeled loss trigger with about 8 percent.

We build several variables in connection with the *peril*. We measure the deal complexity by the variables “Number of Types” and “Number of Locations”. The variables measure how many perils are securitized in how many regions within one CAT bond. Furthermore, we combine different peril types into reasonable groups and generate dummy variables. Here, “Hurricane (HU)” comprises typhoons, tropical cyclones and hurricanes because these names refer to the same storm type that occurs in different regions. The dummy variable “Wind” includes windstorm, winterstorm and thunderstorm, while “Earthquake (EQ)” consists of earthquakes only. Furthermore, we generate peril regions. The region “North America (NA)” comprises all perils that have been securitized in Canada and the United States. The region “Europe (EU)” comprises all perils that have been securitized in Europe while “Japan (JP)” refers to perils in Japan. All other regions are comprised in the variable “Other”.⁴

The initial data set contains *rating* information from S&P, Fitch and Moody’s. These ratings are converted to a point scale where an increase of one point reflects a rating which is one notch worse. If there is more than one rating, the average rating is computed from the point scales. On the basis of this average rating, we determine the rating letter (AAA, AA,..., B), which is relevant for our empirical analysis.

We measure liquidity by *maturity* and *volume* of the CAT bond. The maturity is provided in the initial data set as total maturity at issue in terms of months. We keep this information in the variable “Maturity” in our data set. In addition, we determine the variable “Time to Maturity (TTM)”, which measures the maturity which is left at the time of observation. The volume of the CAT bond is measured in terms of the natural logarithm of volume.

⁴For some CAT bonds there exists a more precise description of location. In North America there are securitized perils in California, North Carolina or Los Angeles. In Europe there exist perils that have been securitized in France or the United Kingdom. Other regions consist of perils in Australia, Mexico and Taiwan.

3.2.2 Macroeconomic Variables

In order to analyze whether there is an influence of capital market developments on CAT bond premiums, we follow two approaches. First, we apply the quarterly return of the index S&P 500 in the variable “S&P500”. Second, we generate the variable “Credit Spreads Corporate (Spreads Corp)” to analyze whether there is a significant correlation between corporate credit spreads and CAT bond premiums. Therefore, we consider credit spreads of U.S. corporates with maturities of one to three years for different rating classes provided by Merrill Lynch. These credit spreads are matched with the CAT bond premiums for identical rating classes. Thus, we are able to measure accurately whether there is an influence of corporate credit spreads on CAT bond premiums.

In order to analyze whether there is an influence of the reinsurance cycle on CAT bond premiums, we analyze the annual return of the “Guy Carpenter Global Property Catastrophe Rate on Line (RoL)⁵ Index”. The respective variable is referred to as “Reins. Index”. The index is presented in Carpenter (2012, p. 4). It is comprised of the output from intensive, annual surveying that Guy Carpenter & Company Ltd. undertakes with their brokers at each data point. It represents their best estimate of price changes on a like-for-like basis year-on-year. The index has been set to 100 points in 1990.⁶

3.2.3 Event Variables

In our observation period from 2002 to 2012, basically two mega-catastrophes occurred. As mentioned above, the most expensive catastrophe for the insurance industry so far was hurricane Katrina in August 2005. In order to measure the effect of hurricane Katrina, first we build a dummy variable “Katrina” as follows:

$$\text{Katrina} = \begin{cases} 1, & \text{if quarter} \geq \text{quarter 4/2005} \\ 0, & \text{if quarter} < \text{quarter 4/2005}. \end{cases} \quad (2)$$

⁵The rate on line is commonly defined as premium divided by the insured limit.

⁶The information is from a private conversation with a managing director of Guy Carpenter & Company Ltd. The analysis is done with paper surveys and phone calls. The data are then reviewed by the managing director and by the catastrophe business practice leaders for the final output.

Second, we separate the influence of Katrina on CAT bonds that have been issued before and after this catastrophe. If a CAT bond has been issued *before* Katrina, it is possible that the default risk increased because multiple events that occur within the risk period are examined cumulatively. Although the bond was marked “distressed” because this effect is strong, some other bonds might be affected, too. Consequently, the CAT bonds that have been issued before hurricane Katrina would have significantly higher secondary market premiums than CAT bonds that have been issued after hurricane Katrina. However, if we observe increased secondary market premiums for CAT bonds that have been issued *after* hurricane Katrina, this can be assigned to a higher risk perception of market participants after the catastrophe event.⁷

Our data set does not contain information on the number of events that are insured in one CAT bond and how these events are examined. However, in order to evaluate and to interpret the effect of hurricane Katrina appropriately, we construct the variable “Pre Katrina Issue” that equals one if the issue date of the CAT bond is prior to Katrina and the observation of the secondary market premium is after hurricane Katrina. Thus, the variable “Pre Katrina Issue” results in

$$\text{Pre Katrina Issue} = \begin{cases} 1, & \text{if issue date} < \text{sep. 2005} \text{ and } \text{quarter} > \text{quarter 4/2005} \\ 0, & \text{else.} \end{cases} \quad (3)$$

Figure 1 displays the construction of the variable “Pre Katrina Issue” and the consequences that can be expected due to the discussion above.

The second mega-event was the financial crisis triggered by the bankruptcy of Lehman Brothers in September 2008. In order to measure the effects of this event, we build the

⁷Note that CAT bonds that already have been distressed due to hurricane Katrina have been eliminated from the original data set.

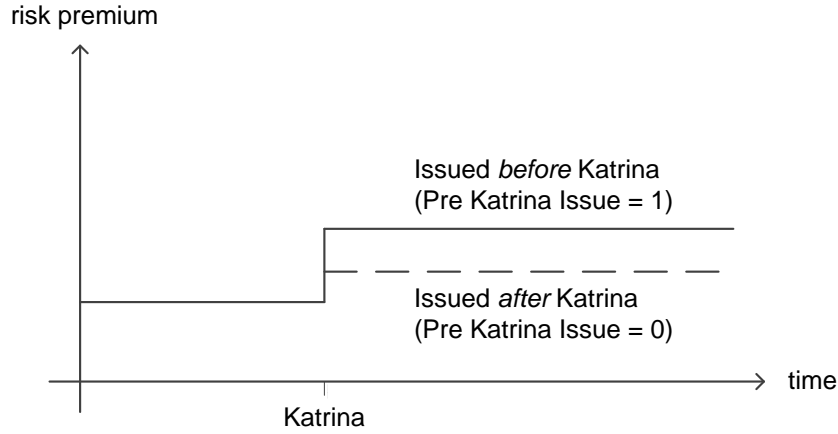


Figure 1: Construction of variable “Pre Katrina Issue”

dummy variable “Lehman” as follows:

$$\text{Lehman} = \begin{cases} 1, & \text{if quarter} \geq \text{quarter 4/2008} \\ 0, & \text{if quarter} < \text{quarter 4/2008}. \end{cases} \quad (4)$$

In addition, in September 2008 hurricane Ike, which is the third largest catastrophe for the insurance industry since 1980, made landfall in the United States. At this stage, we can not affirm with certainty, which of the events affected the CAT bond markets at that time. This will be analyzed subsequently.

3.3 Descriptive Statistics

In Table 1 summary statistics for CAT bond specific dummy variables are presented. Note that the variables regarding *Peril Type* and *Peril Region* can be multiple assigned. Thus, the respective categories do not add up to 100 percent. It can be observed that there is a large number of earthquake insuring CAT bonds with 68.25 percent followed by hurricane insuring CAT bonds with 53.17 percent. Furthermore, it can be observed that in most cases perils in North America are insured. This is conform with observations of Cummins and Weiss (2009). In addition, most CAT bonds are rated “BB”, followed by “B”.

Table 1: **Summary Statistics: CAT bond specific dummy variables for 252 deals.**

Note that Peril Type and Peril Region can be multiple assigned. Thus, the respective categories do not add up to 100 percent.

	Obs.	Percentage
<i>Trigger</i>		
Indemnity	58	23.02
Non-Indemnity	194	76.98
<i>Peril Type</i>		
Hurricane (HU)	134	53.17
Wind	87	34.52
Earthquake (EQ)	172	68.25
<i>Peril Region</i>		
North America (NA)	191	75.79
Europe (EU)	63	25.00
Japan (JP)	48	19.05
Other	13	5.16
<i>Rating</i>		
AA	4	1.59
A	4	1.59
BBB	17	6.75
BB	153	60.71
B	74	29.37

Table 2: **Summary Statistics: Continuous CAT bond specific and macroeconomic variables.**

The statistics are reported on the observation level for variables that are CAT bond specific and vary over time. For variables that are CAT bond specific only, we report the statistics on the deal level.

	Obs.	Mean	Std. Dev.	Min.	q25	q50	q75	Max.
<i>CAT Bond Specific Variables</i>								
Premium	1119	0.061	0.035	0.007	0.036	0.053	0.076	0.192
Expected Loss (EL)	252	0.017	0.014	0	0.008	0.013	0.022	0.061
No. of Locations	252	1.345	0.904	0	1	1	1	4
No. of Perils	252	1.607	0.842	1	1	1	2	4
log(Volume)(USD m)	251	4.241	0.977	0.956	3.807	4.443	5.011	6.473
Maturity	252	35.06	11.48	12	36	36	36	60
TTM	1119	23.77	13.17	0	12	24	36	60
<i>Macroeconomic Variables</i>								
Reins. Index (yearly)	11	0.031	0.155	-0.102	-0.087	-0.060	0.095	0.366
S&P500 (quarterly)	40	0.010	0.093	-0.226	-0.034	0.016	0.071	0.152
Spreads Corp	1119	0.053	0.031	0.004	0.030	0.053	0.072	0.176

In Table 2 summary statistics of continuous variables are presented. We report the statistics on the observation level for variables that are CAT bond specific and vary over

time such as the “Premium”, “TTM” and “Spreads Corp”. For variables that are CAT bond specific only, namely the “EL”, “Number of Locations”, “Number of Perils”, “log(Volume)” and “Maturity”, we report the statistics on deal level. The macroeconomic variables are reported quarterly for the “S&P500” and yearly for the “Reins. Index”.

It can be observed that the mean of premiums is about four times the mean of EL. The variables “Number of Locations” and “Number of Perils” indicate that typically less diverse regions than diverse peril types are insured in one CAT bond. In addition, the range of values of the variable “log(Volume)” varies between 0.96 and 6.47, measured in USD million. Furthermore, the typical CAT bond has a maturity of 36 month, which indicates that maturities of CAT bonds are significantly higher than maturities of traditional reinsurance. In Table 3 the correlations between the above described variables are presented.

Table 3: **Table of Correlations.**

The table presents the pairwise correlations of continuous CAT bond specific and macroeconomic variables.

	Prem.	EL	No.Lc.	No.Pe.	Vol.	Mat.	TTM	Rein.	SP	Sp.Cp.
Premium	1.00									
EL	0.75	1.00								
No. of Loc.	0.28	0.29	1.00							
No. of Perils	0.28	0.07	0.39	1.00						
log(Volume)	0.10	-0.10	-0.05	0.19	1.00					
Maturity	-0.18	-0.22	-0.09	0.04	-0.01	1.00				
TTM	-0.01	-0.07	0.01	0.13	0.07	0.55	1.00			
Reins. Index	0.14	-0.02	0.02	-0.04	-0.02	-0.01	0.10	1.00		
S&P500	-0.01	-0.01	-0.03	0.04	-0.05	0.07	0.07	0.14	1.00	
Spreads Corp	0.46	0.35	0.03	0.05	0.19	0.01	0.03	-0.36	-0.14	1.00

4 Empirical Results

The following empirical analysis consists of several linear approaches with the CAT bond premium always being the dependent variable. First, we determine how much fraction of

variance can maximally be explained by our bond specific or time-dependent data. Second, we analyze the influence of the EL and event dummies. Third, CAT bond specific factors are included in the model in order to verify CAT bond specific hypotheses. Finally, we establish an event analysis where macroeconomic factors are considered as well.

4.1 Benchmark

In order to analyze how much fraction of variance can maximally be explained by bond specific or time-dependent variables, we explain the CAT bond premium by fixed effects as follows:

$$\text{premium}_{it} = \alpha' X_i + \delta' X_t + u_{it}. \quad (5)$$

X_i refers to bond fixed effects meaning that dummy variables are included for every bond. Consequently, an intercept for every bond is generated. X_t refers to time fixed effects which can be quarterly or yearly. For every unit of time a dummy variable is included. Finally, u_{it} refers to the error term that varies over bond and time.

In Table 4 the results of the benchmark analysis on the basis of equation (5) are presented. The goodness-of-fit of the models is measured by the R^2 which is determined on the basis of pooled OLS estimates. It can be interpreted as the part of variation in the dependent variable “premium_{it}” that is explained by the explanatory variables. In model (I.1) we consider bond fixed effects only, thus $X_t = 0$. The R^2 of this analysis is 87.1 percent. Thus, a great part of premium variation can be explained by CAT bond specific information. In model (I.2) not only bond fixed effects X_i but also quarter fixed effects X_t are considered. The corresponding R^2 is 95 percent. When replacing quarter fixed effects by year fixed effects, the R^2 is only slightly lower with 92.3 percent. In comparison, time effects measured by quarter or year are of lower relevance than bond effects for the explanation of premium variance. The same is true for influencing factors that vary over both bond and time as these can explain at most the remaining 5 percent of premium

variation.

Table 4: **Benchmark.**

The R^2 has been determined on the basis of pooled OLS estimates.

	(I.1)	(I.2)	(I.3)
<i>Bond fixed effects</i>	Y	Y	Y
<i>Quarter fixed effects</i>	N	Y	N
<i>Year fixed effects</i>	N	N	Y
Observations	1119	1119	1119
R^2	0.871	0.950	0.923

The above stated results have two implications for our subsequent analysis. First, we only consider year fixed effects instead of quarter fixed effects because the R^2 remains very high when replacing quarter fixed effects by year fixed effects. Second, we apply random effects models to reveal which influencing factors determine the CAT bond premium. We consider random effects models of the following form

$$\text{premium}_{it} = \alpha + \beta'X_i + \gamma'X_{it} + \delta'X_t + a_i + u_{it}, \quad (6)$$

for $i = 1, \dots, n$ CAT bonds and $t = 1, \dots, T$ different points of time. X_i refers to CAT bond specific variables that are not affected by time while X_{it} refers to variables that consider time effects as well. X_t comprises variables that depend on time only. Note that the unobservable individual effect a_i and the error term that varies over time u_{it} are assumed to be random but no distribution function is assumed, thus $a_i \sim IID(0, \sigma_a^2)$ and $u_{it} \sim IID(0, \sigma_u^2)$. In addition, it is assumed that all explanatory variables are independent of a_i and u_{it} for all i, t . Under these assumptions, the random effects estimator is consistent and asymptotically efficient. (Baltagi (2005); Wooldridge (2009)).

For every subsequent analysis we accomplished the Breusch-Pagan test in order to verify whether the assumption of a random effects model is appropriate or if pooled OLS should be applied. The Breusch-Pagan test tests the hypothesis whether the variance of the individual intercept is zero, i.e. whether it can be assumed that there are no CAT

bond specific differences within the units. This hypothesis is rejected for every subsequent model. Thus, it is not appropriate to establish pooled OLS and a random effects model should be applied. In the following, all designated R^2 are overall R^2 that are based on the random effects estimates. In addition, we report the adjusted (adj.) R^2 , which is based on the overall R^2 but adjusts for the number of explanatory variables that are applied in the model.

4.2 Analysis of the Expected Loss

We analyze the influence of the expected loss on the CAT bond premium in the models of Table 5. In model (II.1) we only consider the expected loss as a premium determining factor. We find that, in addition to a constant value, the average CAT bond premium is about two times the expected loss. In the next model (II.2) we include year fixed effects to account for different absolute risk premiums in time and find that the adj. R^2 increases significantly to 64.07 percent. In addition, we include the interaction effect of EL and year in model (II.3) to account for different relative risk premiums in time. The R^2 increases slightly compared to the previous specification. However, the hypothesis that the interaction coefficients equal zero can be rejected on a 99.9 percent level. Thus, the variables of the interaction effect of EL and year are jointly significant.

In the next step, we replace year fixed effects by the event dummies Katrina and Lehman. Using this substitution in specification (II.4), we observe that the R^2 remains at the same level. Thus, it is reasonable to use these event variables instead of time fixed effects. Having identified the interaction effect of EL and year and the event dummies as reasonable variables, we will use them in the following models in addition to the EL and further factors.

4.3 Analysis of CAT Bond Specific Variables

The objective of this section is the verification of CAT bond specific hypotheses. Therefore, we use the interaction effect of EL and year and the event dummies that have been

Table 5: **Impact of the expected loss on premiums.**

The table reports random effects estimates of the expected loss and related variables on the CAT bond premium. Standard errors shown in parentheses are robust to heteroskedasticity. The symbol *** indicates statistical significance at the 0.1% level.

	(II.1)	(II.2)	(II.3)	(II.4)
EL	2.134*** (0.100)	2.098*** (0.102)	3.033*** (0.201)	3.562*** (0.164)
<i>Event dummies</i>				
Katrina				0.006*** (0.002)
Lehman				0.031*** (0.004)
Constant	0.035*** (0.002)	0.037*** (0.002)	0.028*** (0.003)	0.021*** (0.002)
<i>Year fixed effects</i>	N	Y	Y	N
<i>EL-year</i>	N	N	Y	Y
Observations	1119	1119	1119	1119
σ_a	0.0187	0.0177	0.0173	0.0179
σ_u	0.0145	0.0112	0.0110	0.0098
R^2	0.5555	0.6442	0.6629	0.6672
adj. R^2	0.5551	0.6407	0.6564	0.6633

constituted in the previous section as control variables in every model of Table 6. Model (III.1) is only reported for comparison as it is identical to model (II.4) of Table 5. Next, we include CAT bond specific variables X_i that deal with trigger mechanisms and perils. It can be observed that the adj. R^2 with an amount of 77.47 percent is significantly higher for model (III.2) than for model (III.1). Finally, we include variables X_i regarding rating, maturity and volume of the CAT bond. Note, that “Time to Maturity” is a CAT bond specific variable that varies over time, and thus is of type X_{it} . The adj. R^2 of model (III.3) is slightly higher than the one of model (III.2).

We can not confirm the *trigger hypothesis* (H1). In neither model specification we find a significant influence of the dummy variable “Trigger Indemnity”. In addition, the coefficient is close to zero so that the effect is economically insignificant, too. Thus, we have strong support for rejecting the trigger hypothesis. This implies that market imperfections are not imposed by investors with additional premium components. Probably, the above mentioned risk sharing mechanism between sponsor and investor that is included in most indemnity CAT bonds remedies the problem of moral hazard sufficiently. Furthermore, it seems to be important for sponsors to avoid basis risk by applying indemnity trigger

Table 6: **Impact of CAT bond specific variables on premiums.**

The table reports random effects estimates of CAT bond specific variables on premiums. We include the interaction effect of EL and year and the event dummies “Katrina” and “Lehman” as control variables. The base variables are AA, Region NA, EQ for Rating, Peril Region and Peril Type, respectively. Standard errors shown in parentheses are robust to heteroskedasticity. The symbols +, *, **, *** indicate statistical significance at the 10 %, 5%, 1% and 0.1% level, respectively.

	(III.1)	(III.2)	(III.3)
EL	3.562*** (0.164)	3.568*** (0.166)	3.085*** (0.224)
Trigger Indemnity		0.001 (0.003)	0.000 (0.003)
<i>Peril</i>			
Number of Locations		0.009*** (0.002)	0.012*** (0.002)
Number of Types		0.004* (0.002)	0.004* (0.002)
Region EU		-0.011* (0.005)	-0.015** (0.005)
Region JP		-0.011** (0.003)	-0.012*** (0.003)
Region Others		-0.033*** (0.005)	-0.034*** (0.005)
Region Missing		0.008 (0.005)	0.012* (0.004)
Hurricane		0.011*** (0.003)	0.008** (0.003)
Wind		-0.004 (0.004)	-0.002 (0.004)
<i>Rating</i>			
A			0.006 (0.007)
BBB			0.013* (0.006)
BB			0.024** (0.006)
B			0.026** (0.008)
Maturity			-0.000 (0.000)
TTM			0.000 (0.000)
log(Volume)			-0.000 (0.001)
Constant	0.021*** (0.002)	0.005* (0.002)	-0.015+ (0.010)
Control Variables	Y	Y	Y
Observations	1119	1119	1118
σ_a	0.0179	0.0131	0.0128
σ_u	0.0098	0.0098	0.0096
R^2	0.6672	0.7791	0.7882
Adjusted R^2	0.6633	0.7747	0.7826

mechanisms. Based on these findings, we expect that the market share of indemnity triggered CAT bonds will continue to increase. This development has already been identified by Cummins and Weiss (2009), for instance.

Our results strongly support the *complexity hypothesis (H2)*. Both variables “Number of Locations” and “Number of Types” are significantly positive. The variable “Number of Locations” even has a higher coefficient and is more significant than the variable “Number of Types”. Thus, investors tend to prefer CAT bonds that securitize perils in the same region. In addition, they prefer CAT bonds with a lower number of different peril types.

Concerning the peril location, we find that perils that are insured in the European Union, in Japan or other regions, have significantly lower premiums than CAT bonds securitizing events in North America. Furthermore, CAT bonds that insure hurricane events have significantly higher premiums compared to earthquake insuring bonds. This could result from the above mentioned fact that several of the most expensive catastrophes so far have been hurricanes in NA. However, in Section 4.5 we will further analyze whether the identified relation remains valid in general or the effect can be assigned to hurricane Katrina in 2005 or hurricane Ike in 2008.

Our results support the *rating hypothesis (H3)*. We find that investors demand significantly higher premiums for CAT bonds with lower ratings. The coefficients for the rating are increasing as the rating letters decline. Thus, despite all points of criticism concerning the rating of CAT bonds, investors use the rating as additional information for their risk assessment.

Moreover, we find support for the *liquidity hypothesis (H4b)*, i.e. investors do not demand a liquidity premium for CAT bonds. We measure liquidity by the variables “Maturity”, “TTM” and “log(Volume)”. Neither of these variables has a significant influence on CAT bond premiums. This is conform with results of other empirical analyses. Although there is theoretical motivation for a liquidity premium, there is no empirical evidence for the case of CAT bonds.

4.4 Analysis of Macroeconomic Factors

The effects of macroeconomic factors on the CAT bond premium are analyzed in the models presented in Table 7. For an easier comparison of results we repeat model (III.3) in the first column of the table. We use several CAT bond specific variables as control variables in addition to the interaction effect of EL and year and the event dummies Katrina and Lehman, namely the variables Trigger Indemnity, Number of Locations, Number of Types, Peril Type, Peril Region, Maturity, TTM and $\log(\text{Volume})$. In Table 7 we only report the variables that are of interest for the following models.

We include the macroeconomic variables “S&P500” and “Reins. Index” in model (IV.2). It can be observed that there is a significantly positive influence for the yearly return of the reinsurance index and a significantly negative influence for the quarterly return of the S&P500 on the premium. The significantly positive effect of the variable “Reins. Index” remains stable for the following analyses. Thus, we find evidence for our *reinsurance cycle hypothesis* ($H7$), which implies that the development of reinsurance premiums has a positive impact on the development of CAT bond premiums.

The coefficient of the variable “S&P500” is slightly negative. However, if the capital market variable “Spreads Corp” is included in model (IV.3), the coefficient of the “S&P500” becomes positive and insignificant. This results from the negative correlation of the two variables which is -0.14 according to Table 3. Consequently, in model (IV.3) the effects of capital market developments are represented by the variable “Spreads Corp”. The coefficient of the variable “Spreads Corp” is significantly positive. Simultaneously, the influence of the rating variables declines, which can be observed by two facts. First, the coefficients of different rating classes are lower compared to model (IV.1) and (IV.2). Second, the level of significance of the rating variables declines in model (IV.3).

There are two possible arguments for the effect that the influence of the rating declines. First, corporate credit spreads could only be a substitute of the rating class. Second, corporate credit spreads could really add information to the required premium, which would be evidence for a correlation between capital markets and CAT bond premiums.

Table 7: **Impact of macroeconomic factors on premiums.**

The table reports random effects estimates of macroeconomic factors on premiums. The control variables include the interaction effect of EL and Year, the event dummies Katrina and Lehman and the variables Trigger Indemnity, Number of Locations, Number of Types, Peril Type, Peril Region, Maturity, TTM and log(Volume). Standard errors shown in parentheses are robust to heteroskedasticity. The symbols +, *, **, *** indicate statistical significance at the 10 %, 5%, 1% and 0.1% level, respectively.

	(IV.1)	(IV.2)	(IV.3)
EL	3.085*** (0.224)	2.738*** (0.229)	2.244*** (0.245)
<i>Rating</i>			
A	0.006 (0.007)	0.006 (0.008)	0.009 (0.008)
BBB	0.013* (0.006)	0.012+ (0.007)	0.011 (0.007)
BB	0.024*** (0.006)	0.023*** (0.007)	0.016* (0.007)
B	0.026*** (0.008)	0.026** (0.008)	0.015+ (0.008)
<i>Macroeconomic</i>			
Reins. Index		0.012* (0.005)	0.013** (0.005)
S&P500		-0.016** (0.006)	0.008 (0.005)
Spreads Corp			0.235*** (0.042)
Constant	-0.015+ (0.009)	-0.014 (0.009)	-0.018+ (0.009)
Control Variables	Y	Y	Y
Observations	1118	1118	1118
σ_a	0.0128	0.0129	0.0124
σ_u	0.0096	0.0096	0.0093
R^2	0.7882	0.7948	0.8079
Adjusted R^2	0.7826	0.7899	0.8024

The background of the substitution argument is that CAT bond premiums have been matched with the corresponding corporate credit spreads of the same rating class. Thus, the effect of a lower rating on the premium could be included in this variable. However, if the development of corporate credit spreads over time was not important for the premium, the effect of the rating from model (IV.1) and model (IV.2) should remain stable and the coefficient of the variable “Spreads Corp” should not be significant. Though, we observe the opposite effect, i.e. the coefficient of corporate credit spreads are highly significant and the rating is largely insignificant. Consequently, we can conclude that the development of corporate credit spreads over time adds information to the required premium. Thus, we find strong evidence that there is a dependency between capital markets and CAT bond

premiums. In the next section, it is analyzed whether this effect remains valid over time or if there are changes in the case of the financial crisis.

4.5 Analysis of Catastrophe Events

Subsequently, we analyze the impact of natural catastrophes and the financial crisis on risk premiums. The results of the analysis are presented in Table 8. We include the interaction effect of EL and year, the yearly return of the S&P500, the quarterly return of the reinsurance index, and several CAT bond specific variables, namely the Trigger Indemnity, Number of Locations, Number of Types, Peril Region, Rating, Maturity, Time To Maturity, and the natural logarithm of volume as control variables in every analysis. In the first column of Table 8, the last model (IV.3) of the previous analysis is presented for a better comparison of results. We analyze the effects of hurricane Katrina in model (V.2) and (V.3). Subsequently, we analyze the effects of the Lehman event in model (V.4) and (V.5).

We find strong evidence for our *natural catastrophe hypothesis (H5)* in the case of hurricane Katrina. It can be observed in model (V.I) that the coefficient of the dummy variable “Katrina” is highly significantly positive, which indicates that there is a general increase of the risk perception on the CAT bond market. However, it is possible that this effect can be attributed to CAT bonds that have been issued *before* Katrina. Potentially, the secondary market premiums for these CAT bonds do not rise due to an increased risk perception but due to a higher probability of default if events are treated cumulatively in the contracts, as we argued in Section 3.2.3. In order to analyze this relation, we include the variable “Pre Katrina Issue” in model (V.2). This variable measures whether the premium observations *after* hurricane Katrina belong to a CAT bond that has been issued *before* hurricane Katrina. We find that by including this variable, the effect of dummy variable “Katrina” declines and becomes insignificant. Thus, there is no significantly positive effect in general on CAT bond premiums. Instead, the effect can apparently be attributed to bonds that have been issued before Katrina.

Table 8: **Impact of catastrophe events on premiums.**

The table reports random effects estimates of catastrophe events on premiums. We include as control variables the interaction effect of EL and year, Trigger Indemnity, Number of Locations, Number of Types, Peril Region, Rating, Maturity, TTM, log(Volume), Reins. Index and S&P500. Standard errors shown in parentheses are robust to heteroskedasticity. The symbols +, *, **, *** indicate statistical significance at the 10 %, 5%, 1% and 0.1% level, respectively.

	(V.1)	(V.2)	(V.3)	(V.4)	(V.5)
EL	2.244*** (0.245)	2.173*** (0.255)	2.142*** (0.249)	2.589*** (0.246)	2.643*** (0.256)
<i>Peril</i>					
Hurricane	0.009*** (0.003)	0.010*** (0.003)	0.001 (0.002)	0.001 (0.002)	0.001 (0.002)
Wind	-0.001 (0.004)	-0.001 (0.004)	-0.000 (0.005)	-0.001 (0.005)	-0.001 (0.005)
<i>Macroeconomic</i>					
Spreads Corp	0.235*** (0.042)	0.232*** (0.042)	0.237*** (0.042)	0.133* (0.052)	0.122* (0.057)
<i>Events</i>					
Lehman	0.018*** (0.003)	0.019*** (0.004)	0.019*** (0.004)	0.008+ (0.004)	0.005 (0.006)
Katrina	0.005*** (0.001)	0.000 (0.003)	-0.002 (0.004)	-0.000 (0.004)	0.000 (0.004)
Pre Katrina Issue		0.006 (0.004)	0.006 (0.004)	0.004 (0.004)	0.003 (0.005)
<i>Interaction effects with Katrina</i>					
Katrina·HU			0.011*** (0.003)	0.012*** (0.003)	0.010** (0.004)
Katrina·Wind			-0.001 (0.003)	-0.001 (0.003)	-0.001 (0.003)
Pre Katrina Issue·HU			0.005 (0.008)	0.004 (0.008)	0.006 (0.008)
Pre Katrina Issue·Wind			-0.001 (0.006)	-0.002 (0.006)	-0.001 (0.006)
<i>Interaction effects with Lehman</i>					
Lehman·Spreads Corp				0.157** (0.050)	0.170** (0.053)
Lehman·HU					0.004 (0.004)
Lehman·Wind					0.001 (0.003)
Constant	-0.018 (0.009)	-0.012 (0.010)	-0.009 (0.010)	-0.009 (0.010)	-0.008 (0.010)
Observations	1118	1118	1118	1118	1118
σ_a	0.0124	0.0125	0.0123	0.0121	0.0121
σ_u	0.0093	0.0093	0.0092	0.0092	0.0092
R^2	0.8079	0.8083	0.8126	0.8196	0.8209
Adjusted R^2	0.8024	0.8026	0.8064	0.8134	0.8144

In model (V.3) we analyze whether there is a reaction of CAT bond premiums if we focus on issues that insure against hurricanes. Therefore, we include the interaction effects of “Katrina” and “Hurricane” and “Katrina” and “Wind”. We observe that the interaction

effect between “Katrina” and “Hurricane” is highly significantly positive. Simultaneously, the coefficient of “Katrina” remains insignificant and the coefficient of “Hurricane” declines and becomes insignificant. In contrast, the interaction effect of “Katrina” and “Wind” is not significant and the coefficient of variable “Wind” remains stable and insignificant.

Altogether, the implications of these results are as follows. Hurricane Katrina did not lead to higher premiums for all types of perils in general. Instead, only after hurricane Katrina occurred, hurricane perils were imposed with higher risk premiums compared to earthquake perils due to an increased risk perception for hurricanes. In addition, it has been verified that this effect is not completely driven by CAT bonds that have been issued before Katrina and, thus, could actually be affected by the losses of hurricane Katrina. This is conform with our *natural catastrophe hypothesis (H6)*.

We find strong evidence for our *financial crisis hypothesis (H6)* by including the interaction effect of “Lehman” and corporate credit spreads in model (V.4). We include this interaction effect in order to identify whether the influence of corporate credit spreads on the premium can be further explained by the financial crisis, starting with the bankruptcy of Lehman Brothers. The coefficient of the interaction effect is significantly positive. Simultaneously, the coefficient of the variable “Spreads Corp” declines but remains significantly positive. The interpretation of these findings is as follows. While there has only been a relatively small influence of the corporates credit spreads on the CAT bond premium before the bankruptcy of Lehman Brothers, the dependency strengthens after the financial turmoil in the aftermath of the Lehman event. This finding is consistent with our hypothesis (H6).

It has to be stated that the third largest hurricane since 1980 – hurricane Ike – occurred at the same time as the Lehman event. The purpose of model (V.5) is to verify whether the identified effects can really be assigned to the Lehman event or whether they are caused by hurricane Ike. If the effects were caused by hurricane Ike, we would expect that the risk perception for the affected hazard increases after the event as it has been identified in the case of hurricane Katrina. Therefore, we include the interaction effect of “Lehman” and

“Hurricane” and the interaction effect of “Lehman” and “Wind”. Neither of these effects has a significant impact on CAT bond premiums. Thus, we do not find evidence of the natural catastrophe hypothesis (H5) in the case of hurricane Ike. This implies that the risk perception for hurricanes does not significantly increase after hurricane Ike and the previously described effects can indeed be assigned to the Lehman event.

5 Conclusion

In this article, we have analyzed which factors determine the CAT bond premium. In addition, we have analyzed whether and how natural catastrophes or financial crises affect the CAT bond premiums. We verify several CAT bond specific factors that determine the CAT bond premium. Furthermore, we find strong evidence that the financial crisis significantly affected CAT bond premiums. Concerning natural catastrophes we find that after hurricane Katrina, the risk perception for hurricanes rose.

The analysis of the impact of CAT bond specific variables on premiums reveals that the premiums increase if the deal complexity increases in terms of number of insured peril types or regions. In addition, our results support the assumption that investors use rating information for their investment decision. They demand additional premium components if the rating declines. Our results do not verify the expectation in the literature that CAT bonds using the indemnity trigger are imposed by the market with an additional premium. Therefore, we conclude that problems which arise due to asymmetric risk aversion are not of significant importance for the premium of a CAT bond. This could result from incentive provisions that are included in most indemnity trigger CAT bonds. Moreover, there is no empirical evidence for a liquidity premium measured in terms of maturity and volume for the case of CAT bond premiums.

We find that there is a positive dependency of the reinsurance cycle and CAT bond premiums. Thus, CAT bond premiums do have a cyclical behavior that is similar to the reinsurance cycle. Furthermore, we find strong evidence for a positive dependency

of capital market developments measured by corporate credit spreads and CAT bond premiums. This positive dependency strengthens significantly after the bankruptcy of Lehman Brothers that triggered the financial crisis.

Concerning the impact of great natural catastrophe, we have first analyzed the effects of hurricane Katrina. We find that premiums for hurricane insuring CAT bonds are significantly higher than CAT bonds that insure other perils. However, we identify that this effect only arises after hurricane Katrina. In addition, we verify that this effect is not driven by CAT bonds that are actually affected by hurricane Katrina, i.e. bonds that have been issued before the event. Thus, we can conclude that after hurricane Katrina has occurred, CAT bonds with hurricane perils are imposed by investors with additional premium components due to an increased risk perception for hurricanes. However, we do not observe that market participants react with a general mistrust in reported ELs that are based on catastrophe risk models.

Second, we have analyzed the impact of hurricane Ike which occurred at the same time as the bankruptcy of Lehman Brothers. Here, we cannot identify a significant effect on premiums of hurricane insuring CAT bonds that can be assigned to hurricane Ike. Thus, it seems that investors believe that the adjusted risk assessment after Katrina sufficiently accounts for future catastrophes.

An important implication of our results is that not only future natural but also future financial crises might affect CAT bond premiums significantly. Our results revealed that there is a positive dependency between corporate credit spreads and CAT bond premiums. Hence, CAT bonds cannot be regarded as “zero-beta” securities. This dependency even strengthens significantly in the case of the financial crisis. Thus, investors should be aware that there are correlations between CAT bonds and other securities that become even stronger when diversification effects are most valuable, i.e. in extreme market conditions.

Moreover, we have verified several CAT bond specific variables as premium determining factors. An implication of these various factors is that it seems to be important to standardize CAT bonds. Standardization would unify the premium determination and,

consequently, uncertainties in premium calculation could be reduced. Additionally, a standardization of CAT bonds could attract less sophisticated investors, too. Both reasons, the smaller uncertainty and the higher demand, would potentially lead to lower premiums and, thus, be beneficial especially from the originator's point of view.

An important research question addresses the Tohoku earthquake. We could not analyze this event because our data did not reflect the impact of the earthquake sufficiently. If there is enough data, it should be analyzed whether the risk premiums increase after the Tohoku earthquake and whether this has to be attributed to a general mistrust in reported ELs or if this effect can be attributed to earthquake perils only.

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