The Influence of Sponsor Characteristics and (Non-)Events on the Risk Premia of CAT Bonds*

Tobias Götze† Marc Gürtler‡

This study employs CAT bond secondary market data to investigate the impact of sponsor characteristics and natural and economic events on the CAT bond premium. We identify a CAT bond sponsor's diversification, rating, and vertical integration as significant factors affecting the CAT bond premium. Our results suggest that, especially after experiencing large losses investors demand higher premia for CAT bonds with an indemnity trigger. This finding is supported by evidence for the US insurance sector showing that investors take into account sponsors' loss experience when pricing bonds with an indemnity trigger mechanism. Furthermore, we identify a catastrophic event that led to a reduction of CAT bond premia: Hurricane Sandy. Finally, we find that a second negative shock to CAT bond premia was in fact related to the non-occurrence of an event: the 2009 hurricane season.

JEL classification: G01, G12, G22

Keywords: CAT Bonds, Catastrophic Events, Risk Premium

*We thank the participants of the 2017 Workshop of the Working Group on Financial Management and Financial Institutions in the German Operations Research Society for helpful suggestions and comments. We are also thankful to our colleagues at the Department of Finance at Braunschweig Institute of Technology for their productive remarks on this article.

†Tobias Götze, Braunschweig Institute of Technology, Department of Finance, Abt-Jerusalem-Straße 7, 38106 Braunschweig, Germany, t.goetze@tu-bs.de.

‡Contact author: Professor Dr. Marc Gürtler, Braunschweig Institute of Technology, Department of Finance, Abt-Jerusalem-Straße 7, 38106 Braunschweig, Germany, marc.guertler@tu-bs.de.

1 Introduction

CAT bonds, which insure their sponsors against the risk of natural catastrophes, are a capital market-based alternative to conventional reinsurance contracts. In the last 20 years since its inception, the market for these alternative risk-transfer instruments has witnessed continuous growth. Against this background, the pricing of CAT bonds is becoming an increasingly important subject in actuarial and financial science.

Various empirical models have already been developed to examine the influence of bond-specific factors on CAT bond premia (Lane, 2000; Wang, 2000, 2004; Berge, 2005; Dieckmann, 2008; Gatumel and Guegan, 2008; Lane and Mahul, 2008; Lei et al., 2008; Ahrens et al., 2009; Bodoff and Gan, 2009; Papachristou, 2011; Galeotti et al., 2013; Braun, 2016; Gürtler et al., 2016). All of these models contain parameters reflecting the bonds' loss distributions as explanatory variables,[1] and, among these parameters, the most frequently used is the expected loss (EL), which is consistently shown to have a significant positive influence on premia (Major and Kreps, 2003; Berge, 2005; Dieckmann, 2008; Gatumel and Guegan, 2008; Lane and Mahul, 2008; Bodoff and Gan, 2009; Papachristou, 2011; Braun, 2016; Gürtler et al., 2016).[2] Many studies observe differing CAT bond premia by insured region and peril type and detect lower premia for 'exotic' risks that contribute to portfolio diversification (Major and Kreps, 2003; Berge, 2005; Dieckmann, 2008; Lane and Mahul, 2008; Bodoff and Gan, 2009; Papachristou, 2011; Braun, 2016; Gürtler et al., 2016). Lei et al. (2008) and Gürtler et al. (2016) investigate higher premia for multi-peril bonds compared to those for single-peril bonds, which likely stem from a higher degree of complexity. As is the case for standard bonds, the rating characterizes the risk associated with a CAT bond. According to Lei et al. (2008), Braun (2016), and Gürtler et al. (2016) better ratings are associated with lower premia.[3] Braun (2016) is the first to consider the sponsor's influence on premia. The author shows that Swiss Re, the market leader

[1] A CAT bond's loss distribution is estimated by risk modeling companies such as Applied Insurance Research Worldwide, Risk Management Solutions or EQECAT.

[2] Alternative parameters to describe the loss distribution are the probability of first loss (PFL), conditional expected loss (CEL) and probability of last loss (PLL) (the probability of losses suffered by the CAT bond equal to or greater than the limit) (Lane, 2000; Wang, 2000, 2004; Dieckmann, 2008; Lei et al., 2008; Ahrens et al., 2009).

[3] The bond characteristics issue volume, maturity, and time to maturity (TTM) appear to have a minor or insignificant effect on premia (Dieckmann, 2008; Lei et al., 2008; Braun, 2016; Gürtler et al., 2016).

in the CAT bond segment, has to pay a smaller risk premium to investors. Most likely, this result is related to the company's reputation in the market and is a first indication of the relevance of sponsor characteristics for CAT bond pricing. Surprisingly, however, no prior empirical contribution rigorously analyzes the sponsor-specific determinants of CAT bond premia.

The situation is distinct for a financial instrument similar to CAT bonds: asset backed securities (ABS). Research on the market for ABS reflects a relevant influence of the sponsor on ABS prices and performance (Faltin-Traeger et al., 2010, 2011; Faltin-Traeger and Mayer, 2012; Griffin et al., 2014; Liu and Shi, 2014; Piskorski et al., 2015; Griffin and Maturana, 2016). The ABS-related literature points out that sponsor diversification has an effect on the prices and performances of ABS. Faltin-Traeger et al. (2010) find that spreads are higher for more diversified sponsors, but the results obtained by Faltin-Traeger et al. (2011) and Faltin-Traeger and Mayer (2012) show that ABS of more diversified sponsors are able to retain their initial rating over longer time periods. With regard to reputation, a study by Griffin et al. (2014) comes to the conclusion that the securities issued by reputable underwriters have higher portions of capital in default. Another determinant of ABS prices and performances is the sponsor's rating. Faltin-Traeger et al. (2011) and Faltin-Traeger and Mayer (2012) show a positive correlation between the sponsor rating and ABS performance. In contrast, Faltin-Traeger et al. (2010) observe that a better sponsor rating leads to higher ABS spreads. In addition, financial strength measures such as the tier 1 capital ratio and the Altman z-score, are positively related to ABS performance (Faltin-Traeger et al., 2011). The literature also shows that the vertical integration of the sponsor, measured by the affiliation of the sponsor and other participants of the securitization deal, affects ABS prices (Faltin-Traeger et al., 2010, 2011; Faltin-Traeger and Mayer, 2012; Liu and Shi, 2014). According to Faltin-Traeger et al. (2010), ABS spreads are lower when sponsors also service and/or underwrite the ABS deal, and Faltin-Traeger et al. (2011) and Faltin-Traeger and Mayer (2012) find that the affiliation between the sponsor and the servicer/underwriter is causally related to ABS performance. Liu and Shi (2014) extend the evidence regarding the influence of the sponsor-underwriter affiliation to the mortgage backed securities (MBS) market. By comparing sponsors from the domestic and foreign and banking and non-banking sectors, respectively, Faltin-Traeger et al. (2011) and Faltin-Traeger and Mayer (2012) reveal that the sponsor type is another determinant of ABS performance. In addition to the outlined evidence related to sponsor characteristics, Piskorski et al. (2015) and Griffin and Maturana (2016) show that ABS sponsors and underwriters intentionally misreported on securitized loans and mortgages to investors, which negatively affected ABS performance. This finding emphasizes the relevance of the involved parties to the risk inherent in a securitization deal. Overall, the lack of evidence on the CAT bond market and the results obtained on the ABS market motivate a profound analysis of the relationship between sponsor characteristics and CAT bond premia. As both CAT bonds and ABS are structured products based on the method of securitization, they share similarities. These similarities give rise to our first research question: are sponsor characteristics also relevant for the pricing of CAT bonds? The results we obtain in this context indicate that investors reward higher sponsor diversification, better sponsor ratings, and the vertical integration of the sponsor with lower risk premia.

The effect of different trigger types on CAT bond premia has been subject to ongoing controversy. According to the theoretical literature, bonds with indemnity-based trigger mechanisms (like conventional reinsurance contracts) incur higher premia as a result of moral hazard risks and information asymmetries. However, this assumption remains largely unconfirmed by empirical research (Berge, 2005; Lei et al., 2008; Papachristou, 2011; Gürtler et al., 2016). Braun (2016) even finds a negative influence of indemnity triggers on premia and argues that a suitable formulation of incentives in CAT bond contracts restricts the emergence of moral hazard risks and increases the market's acceptance of this trigger type. On the contrary, Dieckmann (2008) identifies higher premia for bonds with an indemnity trigger and shows that this effect can largely be attributed to the occurrence of Hurricane Katrina. However, he only analyzes bond premia directly before and after Hurricane Katrina, and, thus, it is uncertain if the measured effect of the trigger type is temporary or long-term. Thus, there is a clear need to reexamine the influence of the trigger type, and, with our second research question, we investigate the reason for these diverging results in the literature. Regarding this question, we reach two findings. First, the premium level is higher for CAT bonds with an indemnity trigger, and, second, sponsors' loss experience – measured by the one-year-lagged loss ratio – positively influences the risk premia of CAT bonds with indemnity triggers. Accordingly, the positive effect of indemnity triggers on premia is more pronounced when loss ratios are high and when investors in indemnity-triggered CAT bonds take the sponsor's loss experience into account for bond pricing.

With regard to the relationship between CAT bond premia and the overall market environment, the literature agrees that reinsurance prices and CAT bond premia are significantly positively correlated (Major and Kreps, 2003; Lane and Mahul, 2008; Papachristou, 2011; Braun, 2016; Gürtler et al., 2016). In addition, Braun (2016) and Gürtler et al. (2016) reveal a significant positive correlation between CAT bond premia and corporate bond spreads. Gürtler et al. (2016) are able to show that stock market returns also affect CAT bond premia and that both the devastating natural catastrophe Hurricane Katrina and the economically catastrophic bankruptcy of the investment bank Lehman Brothers increase CAT bond premia. This result provides first insights as to how catastrophic events affect the CAT bond market. However, the authors are only able to analyze events that occurred in the US and in addition, they only observe adverse events, because risk premia shifted upward after both Hurricane Katrina and the Lehman Brothers bankruptcy. Whereas evidence on the CAT bond market is restricted to adverse events, we can derive implications from the asset backed commercial paper (ABCP) market. On the one hand, Covitz et al. (2013) show that during the subprime crisis, ABCP programs with weak characteristics were priced out of the market by investors. On the other hand, Duygan-Bump et al. (2013) find a reduction of ABCP spreads after the establishment of emergency lending facilities. Consequently, an examination of possibly comparable effects on the CAT bond market is crucial in order to better understand the price evolution of this asset class. Therefore, we raise our third research question: can the CAT bond market also be affected by events that occur outside the US? In addition, in our fourth research question, we explore whether event-induced downward shifts of premia are equally possible on the CAT bond market and which types of events may trigger such shifts. Surprisingly, with regard to the third question, we do not identify a significant effect of the Tohoku Earthquake that occurred in Japan in 2011. A possible explanation for this result is the small market share of bonds insuring Japanese perils compared to that of bonds insuring US perils. However, regarding the fourth question, we identify two negative shocks to CAT bond premia. In the beginning of 2010, premia decreased relative to the EL because of below average hurricane losses in 2009, and the absolute premium levels of hurricane bonds also decreased. After Hurricane Sandy, premia decreased relative to the EL. This effect was most pronounced for hurricane bonds that additionally experienced a decrease in the absolute premium level.

Our analysis is based on a panel data set on CAT bond secondary market prices, which has three preferential features. First, it is the largest data set on CAT bond prices that has been used as of now. Therefore, it enables a comprehensive analysis of sponsor characteristics without being at risk of small sample bias. Second, with regard to the analysis of catastrophic and economic events, the data set's panel structure allows us to control for unobserved heterogeneity between bonds. Third, as the data covers the period from 2002 to 2017, we are able to analyze a comprehensive set of events, including non-US events, such as the Tohoku Earthquake in Japan, as well. The data set is supplemented by information on bond characteristics (such as EL, issue volume, trigger type, maturity, covered perils, and regions) and sponsor characteristics (such as experience, diversification, rating, and vertical integration). We also include macroeconomic data on stock, reinsurance, and corporate bond prices. Finally, we link the CAT bond-specific information to premium and loss data of US sponsors from the insurance sector. We apply random effects estimation to identify the time-invariant sponsor-specific factors that affect the CAT bond premium and to investigate the influence of the trigger mechanism on the premium. Fixed effects estimation is used to evaluate whether CAT bond premia are related to the sponsor's loss experience and if premia react to catastrophic events. Such events are identified by the panel data threshold regression method developed by Hansen

(1999).

By answering the research questions raised above, this study supplies relevant contributions to actuarial and financial science on the topic of pricing insurance-linked securities (ILS). We reveal the influence of sponsor characteristics on CAT bond premia and point to potential incentives to reduce information asymmetries between sponsors and investors. We reduce the susceptibility to omitted variable bias and enhance the understanding of the contradictory results on trigger mechanisms in the theoretical and empirical literature. In this context, we are the first to link data on CAT bond secondary market prices to data on the regional loss experience of US sponsors from the insurance sector and analyze whether this information is considered by investors in pricing indemnity-triggered CAT bonds. Furthermore, we detect the most significant positive and negative shocks to prices on the CAT bond market and link them to natural and economic events, including non-US events. Altogether, we improve the understanding of pricing on the secondary market for CAT bonds by furnishing new insights on the influences of sponsor characteristics, trigger mechanisms, and catastrophic events on risk premia.

The remainder of this article is structured as follows. In Section 2, we derive eight research hypotheses referring to the sponsor, the trigger mechanism, and the events analyzed in the course of the investigation. Section 3 describes our data set, and the results of our empirical analysis are presented and discussed in Section 4. Finally, we conclude with the results of our work in Section 5.

2 Hypotheses

This study aims to extend the understanding of the determinants of CAT bond premia. Therefore, our goal is to identify the sponsor-specific factors that affect CAT bond premia and to explain the confounding results obtained on the influence of different trigger types. Moreover, we aim to exhibit the CAT bond market's reaction to natural and economic events. For that purpose, in the following, we derive hypotheses on sponsor-specific factors that potentially affect CAT bond premia. Subsequently, we formulate event-specific hypotheses on the effects of natural and economic events on CAT bond premia.

2.1 Sponsor- and Bond-Specific Hypotheses

According to anecdotal evidence provided by Spry (2009), CAT bond investors reward sponsors with strong track records with lower spreads. The author considers this effect to also be causal for the increasing popularity of shelf programs, in which sponsors conduct repeated CAT bond issues and thereby give a positive signal to the capital market. This evidence is underpinned by Braun (2016), who finds significantly lower premia for bonds issued by Swiss Re – an experienced sponsor and user of shelf programs – in an analysis of the primary market for CAT bonds. However, the positive effects of experience are disputed from a risk perspective. An analysis by Griffin et al. (2014) reveals a negative relationship between underwriter reputation and performance on the ABS market.

Experienced CAT bond sponsors are likely to exhibit a higher level of diversification over different peril types and regions than other sponsors are. Diversification on the bond level is already considered in the CAT bond literature, and, according to Lei et al. (2008), Braun (2016), and Gürtler et al. (2016), investors demand a complexity premium for bonds insuring multiple peril types and regions. On the sponsor level, there exists no evidence of the effect of differing degrees of diversification over peril types and regions. Empirical evidence obtained by Faltin-Traeger et al. (2011) and Faltin-Traeger and Mayer (2012) on the ABS market shows that the diversification of an ABS sponsor has a positive effect on ABS performance measured by the time to the first downgrade and the downgrade severity, respectively. Surprisingly, another study of Faltin-Traeger et al. (2010) reveals a contrary effect of diversification at the sponsor level on the ABS initial coupon spread (i.e., higher diversification leads to a higher spread). As the authors unfortunately do not comment on this result, we cannot discuss it in more detail. Despite the partly confounding evidence from the ABS market, we expect diversification to contribute to lower risk premia on the CAT bond market for two reasons. First, it might indicate a strong track record of the sponsor. Second, low sponsor-level diversification might signal the risk that the sponsor may exploit the CAT bond market to remove peak perils from his book of business, whereas, for diversified sponsors, investors might perceive a lower risk of such adverse selection. In light of this evidence, investors supposedly would rather trust in experienced and diversified sponsors, and, possibly, they link these sponsor characteristics to risk-relevant CAT bond characteristics. Therefore, we hypothesize the following:

Experience and diversification hypothesis (H1): Sponsors with greater experience/ diversification in the CAT bond market have to pay lower risk premia.

Braun (2016) argues that the risk premia demanded by investors will also depend on the credit risk perceived for a CAT bond deal. A suitable proxy for sponsor-related credit risk is the rating. Major credit rating agencies (CRAs), such as Standard & Poor's (2012), indicate that they already consider the sponsors' financial strength and, hence, the sponsor-related credit risk when rating the CAT bond itself. This consideration might already suffice for investors. However, no CRA outlines to what degree it considers this risk type in the bond rating. Moreover, especially in view of increased sensitivity towards issuer credit risk caused by the financial crisis (Ejsing and Lemke, 2011; Dieckmann and Plank, 2012; Gilchrist and Zakrajšek, 2012), investors possibly take into account credit risk beyond its consideration by CRAs. In addition, the sponsor's credit quality (i.e., his rating) might be correlated with other factors that investors deem relevant in order to assess the risk inherent in the CAT bond deal. For instance, sponsors with an investment grade rating might provide higher quality or more transparent information on the deal than sponsors with a speculative grade rating or without a rating. The findings of Faltin-Traeger et al. (2011) and Faltin-Traeger and Mayer (2012) on the ABS market support this assumption. They indicate that a better sponsor rating increases the time period over which ABS retain their initial rating and reduces the severity of rating downgrades. The authors further show a positive relationship between ABS performance and measures of sponsor financial strength. This result leads us to conclude that the sponsor-related credit risk and, therefore, the sponsor rating are considerable factors affecting CAT bond risk premia, and we postulate the following:

Rating hypothesis (H2): CAT bond risk premia are higher for sponsors without a rating or with a speculative grade rating than for sponsors with an investment grade rating.

In many CAT bond deals, the sponsor is also participating in the structuring and placement process or is affiliated with the structuring and placement agent.[4, 5] In particular,

[4]See, for example, Lane and Beckwith (2017).

[5]We subsequently consider the sponsor's participation in the structuring and placement process and the sponsor's affiliation with the structuring and placement agent as synonyms.

market-leading sponsors, such as Swiss Re and Munich Re, frequently conduct structuring and placement on their own. Smaller sponsors, on the other hand, contract specialized firms – most often investment banks or the capital market arms of major (re)insurers – for this process (Edesess, 2015). In many deals, multiple agents participate in structuring and placement, and sometimes both the sponsor and other agents are involved.

The sponsor's affiliation with the structuring and placement agent can be interpreted as a form of vertical integration. The ABS-related literature provides evidence for the influence of vertical integration on risk premia. Faltin-Traeger et al. (2010, 2011) and Faltin-Traeger and Mayer (2012) observe the risk premia and performance of ABS when the sponsor is affiliated with the servicer and/or the underwriter of the deal.[6] Sponsor-servicer affiliation has a negative effect on risk premia and a positive effect on performance. In ABS deals, where the sponsor is affiliated with both the servicer and the underwriter, the negative effect on premia is even more pronounced. Liu and Shi (2014) show a negative performance effect of sponsor-underwriter affiliation in the MBS market. The presented results suggest that the sponsor's vertical integration might be relevant for pricing on the CAT bond market as well. However, although sponsor-underwriter affiliation in ABS or MBS deals is comparable to the affiliation of the sponsor and the placement agent in CAT bond deals, the ABS-related literature does not allow for conclusions on the direction of a possible effect on premia. Following the argumentation of Liu and Shi (2014), a decreasing effect on premia might be possible if the investor considers the affiliation of the sponsor and the placement agent as a proxy for the sponsor's know-how of the CAT bond and capital markets and expects better information sharing between the deal participants. In turn, a higher degree of vertical integration of the sponsor might increase the moral hazard risk and reduce incentives to uphold underwriting standards, and, therefore, it might raise premia. Thus, we expect to find an insignificant effect of a sponsor's affiliation with

[6] An underwriter in an ABS deal is comparable to a structuring and placement agent in a CAT bond deal. In the CAT bond literature, these terms are sometimes used as synonyms, as, for example, in Lane and Beckwith (2017). The difference between the two functions is that an underwriter engages in a public offering and purchases securities before offering and reselling them to investors, whereas a structuring and placement agent engages in private placements, in which securities are directly offered to investors (Temel, 2001). Since CAT bonds are usually offered through a private placement (Cummins and Weiss, 2009; Edesess, 2015), we will subsequently use the term structuring and placement agent (or for brevity placement agent).

the placement agent. However, CAT bond deals structured jointly by the sponsor and another agent, are favorable from an investor's standpoint, since they combine the positive aspects of vertical sponsor integration with the benefit of an additional structuring and placement agent, which possibly limits moral hazard risks. Thus, taking all of the mentioned arguments into account, we form the following hypothesis with regard to vertical integration:

> *Vertical integration hypothesis (H3): In CAT bond deals, in which the sponsor adopts the role of the structuring and placement agent together with one or more other agents, risk premia are lower.*

Although the trigger mechanism is already the subject of empirical studies, the literature remains divided regarding its influence on CAT bond premia. Although most empirical studies conclude that the use of an indemnity trigger has no or even a negative effect on premia (Berge, 2005; Lei et al., 2008; Papachristou, 2011; Braun, 2016; Gürtler et al., 2016), Dieckmann (2008) finds higher premia for bonds with an indemnity trigger, especially after Hurricane Katrina. Furthermore, according to the theoretical literature, higher premia for indemnity-triggered bonds are plausible against the background of information asymmetries and moral hazard risk (Lee and Yu, 2002; Dieckmann, 2008; Wu and Chung, 2010). Following the argumentation of Braun (2016), confounding empirical results may stem from the observation of different time periods, especially since in recent years, the emergence of moral hazard risks was restricted through suitable incentive structures in CAT bond contracts. The difference between the results of Dieckmann (2008) and Braun (2016) might signal that the use of indemnity triggers particularly leads to higher premia when investors are exposed to a high level of uncertainty and when they perceive incentive structures in CAT bond contracts to be ineffective in preventing moral hazard. Such a situation most likely occurs after large loss events. Therefore, we hypothesize the following:

> *Trigger hypothesis (H4): CAT bonds with indemnity trigger reveal higher risk premia, and this effect is most pronounced when the CAT bond market faces large losses.*

Existing empirical models of CAT bond premia contain either the EL or other parameters of the bonds' loss distribution (PFL, PLL, CEL) as explanatory variables. A drawback of the EL is its rather static character. The estimate is (usually) not updated when new information on the bond arrives,[7] and, especially in the aftermath of the 2005 hurricane season, mistrust towards EL estimates was growing (Gürtler et al., 2016). Lane and Mahul (2008) already supply evidence of a varying influence of the EL on premia over the bond's life. For these reasons, it seems plausible that investors in CAT bonds with indemnity triggers, for which the theoretical literature identifies the greatest potential for information asymmetries (Lee and Yu, 2002; Dieckmann, 2008; Wu and Chung, 2010), take into account the sponsor's actual exposure and loss experience (in the primary insurance market) with regard to the insured peril and region. Furthermore, the relevance of sponsors' loss experience is related to the relevance of the trigger mechanism, since in (H4) we argue that investors will especially demand higher premia for the use of indemnity triggers after high losses. Additionally, for the majority of sponsors from the (re)insurance sector, premium and loss data are easily available to investors. Thus, we develop the following hypothesis:

> *Loss experience hypothesis (H5): The sponsor's loss experience in the insured region has a significant positive effect on the risk premia of CAT bonds with indemnity triggers.*

2.2 Event-Specific Hypotheses

A major objective of our research is to furnish additional insights on the effects of natural and economic events on CAT bond premia. In prior studies, the discussion focuses on two events: Hurricane Katrina and the bankruptcy of the investment bank Lehman Brothers, which resulted in the financial crisis (Dieckmann, 2008; Ahrens et al., 2009; Gürtler et al., 2016). Two reasons led to the choice of these events. First, anecdotal evidence suggests that the two events caused the most pronounced effect on the CAT bond market. Hurricane Katrina triggered the first default of a CAT bond (KAMP Re), and the Lehman Brothers bankruptcy triggered the defaults of four bonds on interest payments because Lehman Brothers defaulted as the counterparty in a total return swap (Lane and Beckwith, 2010; Braun, 2016). Second, no comparable events were observed during the

[7] The only adjustment of EL estimates commonly made in CAT bond deals is to account for a growing sponsor portfolio over time (Brookes, 2009).

analyzed time periods.

Although Gürtler et al. (2016) show that CAT bond premia significantly rose after both Hurricane Katrina and the Lehman Brothers bankruptcy, their analysis leaves open questions. Since the only catastrophic event identified occurred in the US, the question remains of whether CAT bond premia can be affected by events occurring in other regions. In addition, the assumption that the CAT bond market can only be affected by positive shocks to premia is implausible. As CAT bond premia are strongly correlated with reinsurance premia, which follow a cyclical pattern (Braun, 2016), negative shocks likely can also affect the CAT bond market. One reason for a negative shock might even be a catastrophic event if the CAT bond market showed a strong performance (i.e., a low level of losses) during and after the event. Another reason might be what we subsequently call the non-occurrence of an event. With regard to the case of CAT bonds, a non-occurrence could, for example, be linked to the Atlantic hurricane season. If the US Gulf and East Coasts are not hit by a hurricane in a particular year, CAT bond premia might be negatively affected.

Since our data set covers the period from the second quarter of 2002 to the first quarter of 2017, we are able to analyze the impact of non-US events on CAT bond premia. For that purpose, we measure the effect of the Tohoku Earthquake that occurred in 2011 and caused damages in Japan of a magnitude comparable to that of Hurricane Katrina. Against this background, this event might also have had a significant impact on the CAT bond market. However, the empirical literature related to CAT bonds frequently distinguishes between peak- and non-peak perils,[8] and the results indicate that CAT bonds insuring peak perils obtain higher premia (Major and Kreps, 2003; Berge, 2005; Gatumel and Guegan, 2008; Lane and Mahul, 2008; Bodoff and Gan, 2009; Papachristou, 2011; Braun, 2016; Gürtler et al., 2016). Transferring these results on the Tohoku Earthquake and Hurricane Katrina, the consequences of the Tohoku Earthquake were possibly less severe compared to those of Hurricane Katrina. Nevertheless, CAT bonds insuring Japan

[8]The distinction between peak and non-peak perils is attributable to the fact that the majority of CAT bonds insure perils in the US. As a consequence, US hurricanes and earthquakes are classified as a peak peril, whereas non-peak perils are related to other locations and therefore contribute to a CAT bond portfolio's diversification (e.g., a Japanese Earthquake) (Bodoff and Gan, 2009; Braun, 2016).

earthquake risks have a considerable market share,[9] and in the case of Muteki, a Japan earthquake bond issued by Munich Re, a notable default with a total principal loss of 300m USD resulted from the earthquake (Artemis, 2011a).[10] Taking into account both the insights gained from the literature and the actual impact of the event, we derive the following hypothesis related to the Tohoku Earthquake:

Tohoku hypothesis (H6): After the Tohoku Earthquake, CAT bond risk premia increased significantly.

Faias and Guedes (2017) test the presence of Bayesian learning on the CAT bond market in a simulation study and offer a possible justification for why catastrophic events might also cause downward shifts of premia. In their analysis, the authors show that a positive performance surprise during a devastating event attracts new investors to the CAT bond market, which in turn leads to lower risk premia (Faias and Guedes, 2017). A natural example of a positive performance surprise is Hurricane Sandy, which hit the US East Coast in 2012. Sandy was a devastating catastrophe and caused major losses to the US economy as a whole and, especially, to its insurance sector, but unlike Hurricane Katrina and the Tohoku Earthquake, it did not cause a default on the CAT bond market (Artemis, 2013b). The high robustness of CAT bonds towards Sandy might have been a signal of market strength or a positive performance surprise to investors. This assumption is also supported by anecdotal evidence of a fast market recovery after Hurricane Sandy, which is attributed to the increased transparency of (re)insurance markets and the growing quality of risk models (Artemis, 2012). The analysis of Sandy is insightful in view of the heterogeneous evolution of the conventional reinsurance market and the ILS market after the 2005 hurricane season. Whereas, global gross reinsurance premia showed only a minor increase between 2006 and 2013 (International Association of Insurance Supervisors, 2017), the outstanding volume in the ILS market more than doubled from 9.2 billion USD to 20.8 billion USD in the same period (Artemis, 2017). We assume that this increase

[9] More details on the distribution of CAT bond issues over peril types and regions are presented in Table 1 in the summary statistics of our empirical analysis.

[10] Additionally, the earthquake was a first qualifying event for several bonds providing second event coverage. Consequently, no losses from the Tohoku earthquake occurred to investors in those bonds, but they were at risk of any further qualifying event during the bonds' life after the event (Artemis, 2011c).

was connected to the higher importance of CAT bonds relative to traditional reinsurance at the time of Sandy. In light of the presented evidence, we hypothesize the following:

Market performance hypothesis (H7): After a large catastrophic event that did not cause defaults on the CAT bond market, risk premia decrease.

Finally, we want to examine whether the CAT bond market can be affected by the non-occurrence of an event. A US hurricane is probably the most meaningful event for the CAT bond market, and, at the same time, it has a considerable probability of occurrence. The US hurricane season lasts approximately from July until November, and, in an average season, the Eastern and Gulf states are hit by one major hurricane. Whereas the 2004, 2005, and 2012 seasons caused severe damages in the range of 51, 145, and 56 billion USD, respectively, the 2009 season was passed without any event causing catastrophic losses[11] in the US and without major losses in the Caribbean or in Central America (National Hurricane Center, 2017). The great variance in the damages from succeeding hurricane seasons raises the question of whether investors' learning processes take into account not only positive performance experiences after the occurrence of natural catastrophes, as discussed by Faias and Guedes (2017), but also positive performance experiences stemming from the non-occurrence of natural catastrophes. To investigate this question, we hypothesize the following:

No event hypothesis (H8): If the Atlantic hurricane season passes without the occurrence of any major event and without large losses, CAT bond risk premia decrease.

3 Data

3.1 Sample Selection

In our analysis, we use data on 585 CAT bonds issued between December 1997 and March 2017 and traded on the secondary market. We observe secondary market premia of these bonds starting in the second quarter of 2002. The premia, which form the dependent variable of our analysis, can be described as average yield spreads over the LIBOR on a

[11] According to the Property Claim Service, an event is catastrophic if it causes more than 25 million USD insured property losses (Born and Viscusi, 2006).

quarterly basis. The data is obtained from Lane Financial LLC.[12] This ILS consulting firm also provides information on the bonds' EL, issue volume, term, sponsor, and placement agent. Data on the trigger mechanism, insured peril types and regions are obtained from the Artemis Deal Directory and from Aon Benfield.

We exclude all observations with missing or implausible data from our data set (e.g. observations where the EL does not equal the product of the PFL and the CEL) as well as bonds that were labeled distressed. For such bonds, a triggering event and, thus, a default have most likely occurred. Therefore, pricing for these bonds follows the loss estimation process, which is not a subject of our analysis. In order to utilize a preferably broad data set, we exclude these bonds only from the moment they became distressed. Finally, we exclude bonds insuring mortality risks.

The challenge of seasonality arises for peril types such as hurricanes and wind. To deal with this challenge, we follow the procedure suggested by Gürtler et al. (2016) and only include observations for bonds where the TTM corresponds to a multiple of a full year. The remaining data set that is used for the empirical analysis consists of 461 CAT bonds with 1,951 premium observations.

3.2 Variables

Sponsor-specific Variables

The goal in the first part of the empirical analysis is to identify sponsor-specific factors that influence CAT bond premia. For that purpose, we introduce sponsor-specific variables in the following. The variable "Experience" measure the effect of a sponsor's experience on bond premia, as suggested in (H1), and is modeled as the number of CAT bonds already issued by the sponsor at the observed point in time. The variable "Diversification" is defined as the number of different combinations of peril types and locations insured by the CAT bonds of the same sponsor at the observed point in time.

Furthermore, the sponsor rating is considered to analyze the rating hypothesis (H2).

[12] The spread is calculated by Lane Financial LLC in the following manner. First, bid and ask quotes are surveyed from several dealers. Second, the values are averaged per dealer to obtain a single yield spread per dealer. Third, the quarterly average spreads are averaged again across dealers, yielding the dependent variable of the analysis. The dealers providing secondary market spreads are Aon, BNP Paribas, Cochran Caronia, Goldman Sachs, Lehman Brothers, Merrill Lynch, and Swiss Re. Over time, there were slight changes among the dealers (Lane and Beckwith, 2006, 2009, 2010).

We obtain sponsor ratings from the four CRAs, that is, S&P, Fitch, Moody's, and AM Best, from Thomson Reuters Eikon. For Japanese sponsors, we additionally consider the rating of the Japanese Credit Rating Agency. Ratings are transformed to a point scale and averaged across agencies. We assign the ratings to the three classes, investment grade, speculative grade, and no rating and establish a dummy variable for each of those classes in order to reasonably contain the number of variables.

Additionally, to test the validity of the vertical integration hypothesis (H3), we first establish a dummy variable called "Sponsor in Structuring and Placement" that equals one if the sponsor is affiliated with the structuring and placement agent. Second, we introduce a dummy variable called "Sponsor and Other in Structuring and Placement" that equals one when structuring and placement is conducted jointly by the sponsor and one or more other agent(s).

We establish a dummy variable called "Trigger Indemnity" to measure the effect of indemnity triggers on CAT bond premia with respect to the trigger hypothesis (H4).

We introduce a variable called "Loss Ratio" given by the ratio between regional premia earned and losses incurred by sponsors from the US insurance sector to test hypothesis (H5) regarding the sponsor's loss experience. To construct the variable, we match the premium and loss data with our CAT bond data set and aggregate premia and losses over insurers' business lines with a high exposure to catastrophe risk.[13] For CAT bonds that insure perils in the US, we additionally aggregate the data over the insured states.[14] We also take into account the level of reinsurance coverage purchased by those sponsors. Therefore, the variable "Reinsurance Ratio" is defined as reinsurance ceded divided by the sum of premia written and reinsurance assumed from other companies (Born and Klimaszewski-Blettner, 2013). Data on premia, losses, and reinsurance are obtained from the National Association of Insurance Commissioners (NAIC) and are available for the time period from 2004 to 2015.

[13]Following Born and Klimaszewski-Blettner (2013) we consider the business lines "Homeowner Multi Peril", "Commercial Multi Peril", "Allied Lines" and "Fire". In CAT bond deals that insure earthquake risk, we additionally include the business line "Earthquake".

[14]In general, it is possible that bonds insure perils in the entire US, in a group of federal states, or exclusively in one state.

Macroeconomic and Event Variables

A set of macroeconomic variables is introduced to analyze the influence of catastrophic and economic events. First, we consider the quarterly return of the S&P500. Next, we introduce the variable "Reinsurance Index (Reins. Index)" as the annual relative change of the Guy Carpenter Global Property Catastrophe Rate on Line Reinsurance Price Index. The index is described in more detail in Carpenter (2012). To construct the index, Guy Carpenter & Company Ltd. conducts annual surveys of its brokers.[15] Furthermore, we include the variable "Corporate Credit Spread (Corp. Spread)", which is based on the credit spreads of US corporate bonds of different rating classes and maturities between one and three years obtained from Merrill Lynch. The variable "Corp. Spread" is constructed by matching the spreads with bonds in the identical rating class.[16]

In addition, five event dummy variables are defined. We consider dummy variables for the 2005 hurricane season and the financial crisis (i.e., the bankruptcy of Lehman Brothers) in September 2008. In order to test the influence of non-US events on the CAT bond market, we also include a variable for the Tohoku Earthquake in the first quarter of 2011. To examine whether CAT bond investors react to a robust market performance after natural catastrophes, we introduce a dummy variable for Hurricane Sandy, which made landfall in the fourth quarter of 2012. Finally, a dummy variable for the 2009 hurricane season is employed to review how the non-occurrence of a catastrophic event affects the CAT bond market.[17] Consequently, the set of considered variables is defined

[15] According to information given in a private conversation by a managing director of Guy Carpenter & Company Ltd., the annual analysis is carried out through paper surveys and phone calls. The resulting data are reviewed by the managing director and by the catastrophe business practice leaders to obtain the final output.

[16] This matching procedure is difficult for the CAT bonds in our sample without rating, since a suitable corporate bond index that could be assigned to those bonds cannot be determined intuitively. To overcome this obstacle, we compare the PFLs of the CAT bonds in our sample by rating class. For bonds without rating, we find that the mean value of the PFL is slightly below the mean value for "B"-rated bonds. The median is slightly above the median for "BB"-rated bonds. Consequently, the suitable candidates for the corporate credit spread to be assigned to CAT bonds without a rating are the spreads of either "B" or "BB" corporate bonds. Therefore, in all subsequent models in which we apply the "Corp. Spread" variable, we use the "B" spread as a reference for bonds without a rating. However, all of our subsequent results' are also robust to the use of the "BB" spread for bonds without a rating.

[17] Although event variables are defined at this stage, the actually relevant events are identified endogenously later on, using the threshold regression method for panel data developed by Hansen (1999) and considering all possible alternative events.

as follows:

$$\text{Season 2005} = \begin{cases} 1, & \text{if quarter} \geq 1/2006, \\ 0, & \text{if quarter} < 1/2006. \end{cases} \tag{1}$$

$$\text{Lehman} = \begin{cases} 1, & \text{if quarter} \geq 4/2008, \\ 0, & \text{if quarter} < 4/2008. \end{cases} \tag{2}$$

$$\text{Season 2009} = \begin{cases} 1, & \text{if quarter} \geq 1/2010, \\ 0, & \text{if quarter} < 1/2010. \end{cases} \tag{3}$$

$$\text{Tohoku} = \begin{cases} 1, & \text{if quarter} \geq 2/2011, \\ 0, & \text{if quarter} < 2/2011. \end{cases} \tag{4}$$

$$\text{Sandy} = \begin{cases} 1, & \text{if quarter} \geq 1/2013, \\ 0, & \text{if quarter} < 1/2013. \end{cases} \tag{5}$$

3.3 Descriptive Statistics

Table 1 presents the summary statistics on the CAT-bond- and sponsor-specific nominal and ordinal variables used in the subsequent analysis. Roughly one third of the bonds in our data set contains an indemnity trigger. Th dominant peril types insured are hurricanes and earthquakes and the majority of bonds insure North American risks. The most frequent rating of CAT bonds is "BB".

Around 83 percent of CAT bond sponsors exhibit investment grade ratings.[18] The remaining sponsors either have a speculative grade rating (around 9 percent) or they are not rated (around 8 percent). Sponsors participate in the structuring and placement of 38 percent of the CAT bond deals, whereas the remaining deals have other structuring and placement agents. In only 8 percent of deals, structuring and placement is conducted jointly by the sponsor and one or more other agent(s).

Table 2 shows the summary statistics of the cardinal variables applied in the empirical

[18]Following the methodology of the CRAs S&P, Fitch, and Moody's, we define all ratings above "BBB" or the Moody's equivalent "Baa" as investment grade (Moody's, 2016; Standard & Poor's, 2016; Fitch, 2017).

Table 1: **Summary Statistics: CAT-Bond- and Sponsor-Specific Nominal and Ordinal Variables for 461 Deals.**
Note that except the sponsor rating, the variables are time-invariant and therefore reported at the deal level. The sponsor rating is reported at the observation level. Since it is possible that multiple peril types and peril regions are assigned to one bond, the category percentages do not add up to 100 percent for these groups of variables. With regard to structuring and placement, the category 'Sponsor and Other' describes the number of deals, in which apart from the sponsor, one or more other agent(s) participate in structuring and placement.

	Obs.	Percentage
Trigger		
Indemnity	154	33.41
Non-Indemnity	307	66.59
Peril type		
Hurricane (HU)	281	60.95
Wind	167	36.23
Earthquake (EQ)	297	64.43
Peril region		
North America (NA)	347	75.27
Europe (EU)	133	28.85
Japan (JP)	83	18.00
Other	43	9.33
Rating		
AA	4	0.87
A	4	0.87
BBB	18	3.90
BB	218	47.29
B	105	22.78
No Rating	112	24.30
Sponsor Rating		
Investment Grade	1623	83.19
Speculative Grade	176	9.02
No Rating	152	7.79
Structuring and Placement		
Other only	288	62.47
Sponsor	173	37.53
thereof Sponsor and Other	37	8.03

analysis. Time-variant bond- and sponsor-specific variables ("Premium", "TTM", "Diversification", "Experience", and "Corp. Spread") are reported at the observation level and time-invariant variables ("EL", "Number of Locations", "Number of Perils", "Volume", "Maturity") are reported at the issue level. Among the macroeconomic variables, the variable "Reins. Index" is reported yearly, and the variable 'S&P500' is reported quarterly. The variables "Loss Ratio" and "Reinsurance Ratio" are reported at the observation level for the subsample of US insurers in the time period between 2004 and 2015.

The mean of the premia is 6 percent and is almost three times greater than the mean of the EL. A bond insures on average 1.4 locations and 1.8 perils and has an average volume of 123 USD million. The average maturity is three years. Over all of the observations in the data set, the mean sponsor experience is twelve CAT bond deals, and the mean diversification is roughly six peril/location-combinations.

In the subsample of US insurers, we observe annual loss and reinsurance ratios. The mean loss ratio amounts to 59.7 percent, whereas reinsurance coverage is 4.7 percent on average. Interestingly, the data contains some observations where the loss ratio is negative as a result of negative losses incurred. All of these observations can be assigned to Swiss Re and its losses in the direct insurance business in the years 2006 and 2011. Negative losses can result if the losses for unsettled claims from the prior year are overestimated (Wisconsin Office of the Commissioner of Insurance, 2012).

Table 2: **Summary Statistics: Cardinal CAT-Bond-, Sponsor-Specific and Macroeconomic variables.**
The statistics for variables that are CAT bond- or sponsor-specific and vary over time are reported at the observation level. For variables that are CAT bond or sponsor-specific and constant over time, the statistics are reported at the deal level. The variables Loss Ratio and Reinsurance Ratio are based on the subsample of US insurers in the time period between 2004 and 2015.

	Obs.	Mean	Std. Dev.	Min.	q25	q50	q75	Max.
CAT-bond-specific variables								
Premium (in %)	1951	5.98	4.11	0.67	3.20	4.96	7.36	35.67
Expected Loss (EL) (in %)	461	2.26	2.22	0.00	0.86	1.40	2.98	14.75
No. of Locations	461	1.44	0.90	0.00	1.00	1.00	2.00	4.00
No. of Perils	461	1.77	1.12	1.00	1.00	1.00	2.00	5.00
Volume (in USD million)	461	122.92	120.95	2.10	50.00	100.00	155.00	1500.00
Maturity (in years)	461	3.01	0.97	1.00	3.00	3.00	3.50	5.08
TTM (in years)	1951	2.06	1.11	-0.75	1.00	2.00	3.00	5.08
Sponsor-specific variables								
Diversification	1951	5.83	4.40	1.00	1.00	5.00	8.00	16.00
Experience	1951	12.06	12.88	0.00	3.00	6.00	18.00	52.00
Loss Ratio (in %)	841	59.73	42.02	-15.38	34.83	52.73	70.65	218.01
Reinsurance Ratio (in %)	841	4.70	7.52	0.00	0.20	2.02	6.21	63.81
Macroeconomic variables								
Reins. Index (yearly) (in %)	16	-0.06	13.78	-11.20	-8.82	-6.76	6.42	36.59
S&P500 (quarterly) (in %)	60	1.53	7.92	-22.56	-2.10	2.05	5.78	15.22
Corp. Spread (in %)	1951	5.41	2.60	0.39	3.54	5.31	6.84	17.57

Table 3 presents the correlation between the variables used in the empirical analysis. We identify a strong correlation between the EL and the premium, indicating that the EL has a strong influence on CAT bond premia. Among the further bond-specific factors, the variables “No. of Locations” and “No. of Perils” are positively correlated with the premium. The variables “log(Volume)”, “Maturity”, and “TTM” negatively correlate with the premium. The sponsor-specific variables “Diversification” and “Experience” are both positively correlated with the premium and with the EL. By construction, the two variables are also strongly correlated to each other. Moreover, as assumed in (H1), the strong co-movement of "Experience" and "Diversification" indicates that they are two concomitant characteristics of CAT bond sponsors. Sponsors insuring a high number of peril-location combinations in their current CAT bond portfolios also tend to have substantial experience from prior CAT bond deals. We account for this high correlation in the subsequent analysis, as it might expose our model to multicollinearity problems when we attempt to measure the two effects jointly. Interestingly, both "Diversification" and "Experience" are negatively correlated with "log(Volume)". We believe this result to be a consequence of the increasing use of shelf programs for repeated CAT bond issues, especially by the larger and, thus, more experienced and diversified CAT bond sponsors (Braun, 2016). Those programs allow quick execution and lower transaction costs, and, for those reasons, their volumes tend to be smaller than those in traditional deals (Braun, 2016).

Table 3: **Table of Correlations.**
This table presents the pairwise correlations of cardinal CAT-bond-, sponsor-specific and macroeconomic variables.

	Prem.	EL	No.Lc.	No.Pe.	Vol.	Mat.	TTM	Div.	Exp.	Rein.	S&P	Sp.Cp.
Premium	1.00											
EL	0.79	1.00										
No. of Loc.	0.31	0.32	1.00									
No. of Perils	0.29	0.22	0.36	1.00								
log(Volume)	-0.15	-0.15	-0.05	0.07	1.00							
Maturity	-0.25	-0.19	-0.07	0.08	0.11	1.00						
TTM	-0.03	-0.05	0.02	0.09	0.11	0.54	1.00					
Divers.	0.21	0.26	0.12	0.06	-0.41	-0.31	-0.27	1.00				
Exp.	0.16	0.28	0.04	-0.02	-0.30	-0.23	-0.29	0.82	1.00			
Reins. Index	0.25	0.04	-0.00	-0.03	-0.16	-0.10	0.03	0.13	0.05	1.00		
S&P500	-0.01	0.04	0.03	0.06	0.01	0.07	0.07	-0.07	-0.04	0.09	1.00	
Corp. Spread	0.31	0.23	0.04	0.06	0.15	0.01	0.03	-0.09	0.04	-0.16	-0.32	1.00

4 Empirical Results

In the empirical analysis, we estimate a range of linear models with the CAT bond premium as the dependent variable. First, we analyze the influence of sponsor-specific factors on premia. Second, we review whether information on sponsor exposure is considered by investors on the CAT bond market for a subset of our data. Third, we carry out an analysis of how natural and economic catastrophes affect CAT bond premia.

4.1 Analysis of Sponsor-Specific Variables

This subsection aims at identifying sponsor characteristics that influence the premia of CAT bonds to test the sponsor-specific hypotheses derived above. Furthermore, since the literature provides contradictory evidence with regard to the influence of the trigger mechanism, we also analyze if the use of indemnity triggers influences CAT bond premia. As the considered sponsor-specific variables are (largely) time-invariant, we apply random effects estimation. The analysis is based on the following model.[19]

$$\text{premium}_{it} = \beta' X_i + \gamma' Y_t + \delta' Z_{it} + a_i + u_{it}, \tag{6}$$

for CAT bond $i = 1, ..., n$ and points in time $t = 1, ..., T$. X_i refers to time-invariant bond- and sponsor-specific variables (e.g., the variable "Sponsor in Structuring and Placement"). Z_{it} refers to variables that vary by bond (sponsor) and time, similar to the variable "TTM" of a bond. Because the literature mentioned in Section 1 already thoroughly analyzed bond-specific factors, our focus is on the sponsor-specific variables included in X_i and Z_{it} and the variable "Trigger Indemnity". The additional bond-specific variables enter the models as controls to reduce the risk of omitted variable bias. Y_t contains variables that only vary over time, which, in this model, are year fixed effects. A caveat of the random effects model is its strong assumptions. A consistent and asymptotically efficient random effects estimator is only obtained if the unobservable individual effect a_i and the error term u_{it} are random and independently and identically distributed, with μ_a and σ_a as the mean and standard deviation of a_i and with zero and σ_u as the mean and standard deviation of u_{it}. Additionally, all of the explanatory variables X_i, Y_t, and Z_{it} have to be independent of a_i and u_{it} for all i, t (Baltagi, 2013; Wooldridge, 2015). In Equation (6), the omission of a time-invariant variable that is correlated with the considered influencing factors would lead to biased estimates. The assumption of independence between the explanatory variables

[19] Before establishing the model in Equation 6, we conducted a benchmark analysis to identify the share of the variance in CAT bond premia that can be explained by bond-specific, by sponsor-specific, and by time-dependent variables. For reasons of brevity, the results of that analysis are not presented here but are available from the authors on request. The analysis furnished two important implications. First, year fixed effects provide a good approximation of the variance in CAT bond premia over time. Second, time effects explain only a minor portion of the variance of CAT bond premia compared to time-invariant bond- and sponsor-specific effects, which leads us to apply random effects estimation to reveal these influencing factors, focusing on the characteristics of the CAT bond sponsor.

and both a_i and u_{it} cannot be tested. Therefore, we consider a wide set of bond-specific controls to account for all economically relevant influencing factors likely to be correlated with the sponsor-specific variables.

For the two models presented in the following, a Breusch-Pagan test (BP test) is applied to verify that a random effects model is appropriate compared to a pooled OLS model.[20] Both models reject the test's null hypothesis of zero variance σ_a of the individual intercept at a high significance level (p < 0.1%). Hence, random effects estimation is deemed to be more appropriate than pooled OLS estimation.

For the analysis of sponsor-specific variables, we establish models (I.1) and (I.2) in Table 4. These models represent two different versions of the random effects model in Equation 6. For each model, we report the value of the overall R^2. On this basis, an adjusted R^2 is also reported to correct for the number of explanatory variables in the respective model. Bond-specific control variables comprise the EL, the number of insured locations and peril types, the maturity, the TTM, and the logarithm of volume. Additionally, dummy variables are included for different peril regions and peril types as well as for the bond rating categories exhibited in Table 2. In addition, we control for year fixed effects and interaction terms between the year and the EL. The comprehensive set of controls confines the risk of omitted time-invariant influencing factors, which is also documented in the high R^2-values of both models, indicating that we can explain more than 85 percent of overall variance.

Among the sponsor-specific variables in model (I.1), "Experience" has no significant effect on premia. In contrast, "Diversification" has a significant effect (p < 0.1%) on premia. An additional combination of location and peril type leads to a premium that is lower by 13 basis points (bp). This evidence strongly supports hypothesis (H1) on sponsor diversification. As anticipated by hypothesis (H2), the sponsor rating has a significant influence on premia. The model includes dummy variables for sponsors with a speculative grade rating and those without a rating. Sponsors with an investment

[20] The implemented test is precisely a modified version of the BP test for unbalanced panel data suggested by Baltagi and Li (1990). The Lagrange multiplier statistic resulting from the test is reported in the subsequent regression table together with the statistical significance of σ_a.

grade rating form the base category. Compared to sponsors with an investment grade rating, sponsors with a speculative grade rating have to pay a higher risk premium of 49 bp. For sponsors without a rating, this effect is even more pronounced (61 bp). The effects of both rating categories are statistically significant ($p < 5\%$), whereas the difference between the coefficients obtained for the two classes (speculative grade and no rating) is statistically insignificant.[21] As mentioned above, structuring and placement are characterized by two dummy variables. The first equals one if the sponsor is involved in structuring and placement, and the second equals one if, in addition to the sponsor, another agent is participating in structuring and placement. Consistent with the vertical integration hypothesis (H3), the affiliation of the sponsor and placement agent has no significant influence on premia. In contrast, in deals where structuring and placement are conducted jointly by the sponsor and another agent, we find that the risk premium is lower by 81 bp ($p < 5\%$), which confirms the vertical integration hypothesis (H3). Finally, the variable "Trigger Indemnity" has a significant coefficient ($p < 5\%$), suggesting that for bonds with indemnity triggers, premia are 41 bp higher. This result supports the trigger hypothesis (H4).

In Section 3, we demonstrated the strong co-movement between the variables "Experience" and "Diversification". Taking into account this univariate result and the fact that "Diversification" has a significant effect, but "Experience" does not, we slightly adapt model (I.1) and exclude the insignificant "Experience" variable in model (I.2). In that case, the "Diversification" variable remains significant, and the effect size decreases marginally to 12 bp.[22] Therefore, the results obtained from models (I.1) and (I.2) support hypothesis (H1) but indicate that the measured effect on premia is the result of the

[21] We also analyzed sponsor characteristics with a more granular set of rating classes in our model. The consideration of dummy variables for the rating classes "AAA", "AA", "A","BBB", "BB and worse" and "No rating" showed no systematic differences between rating classes within the investment grade segment or the speculative grade segment.

[22] Comparing models (I.1) and (I.2), it can be noted that the exclusion of the "Experience" variable leads to a higher adjusted R^2 but also that the R^2 is increasing. This result stems from the calculation of goodness of fit. The exhibited R^2 corresponds to Equation 6, but the parameter estimation with random effects is based on quasi-demeaned data (i.e., the random effects transformation of Equation 6). Thus, the calculated R^2-values do not have all of the ordinary properties of the OLS R^2, and the inclusion of additional variables does not necessarily increase the R^2 (StataCorp, 2015; Wooldridge, 2015).

sponsor's diversification and not his experience.[23] All in all, models (I.1) and (I.2) have only minor differences.

Table 4: **Impact of Sponsor-Specific Variables on CAT Bond Premia.**
This table reports random effects estimates of sponsor-specific variables on premia (in %). The set of cardinal bond-specific control variables contains the EL, the number of insured locations and peril types, the maturity, TTM and the log(Volume). Furthermore, dummy variables are included for different peril regions and peril types as well as for different bond rating categories. Standard errors are clustered by bonds and robust to heteroscedasticity. p-values are shown in parentheses. The symbols †, *, **, and *** indicate statistical significance at the 10%, 5%, 1%, and 0.1% level, respectively.

	(I.1)	(I.2)
Experience	0.004	
	(0.7421)	
Diversification	-0.127***	-0.123***
	(0.0002)	(0.0000)
Sponsor Rating		
Speculative Grade	0.492*	0.487*
	(0.0322)	(0.0338)
No Rating	0.613*	0.612*
	(0.0218)	(0.0216)
Sponsor in Structuring and Placement	0.332	0.414
	(0.2900)	(0.1725)
Sponsor and Other in Struct. and Plcmt.	-0.809*	-0.826*
	(0.0231)	(0.0175)
Trigger Indemnity	0.410*	0.407*
	(0.0271)	(0.0280)
Bond-specific controls	yes	yes
Year fixed effects	yes	yes
EL × year	yes	yes
Observations	1951	1951
μ_a	3.117***	3.070**
σ_a	1.3569***	1.3572***
LM statistic	497.14	507.54
σ_u	1.0530	1.0559
R^2	0.8527	0.8529
Adjusted R^2	0.8485	0.8488

4.2 Analysis of Exposure Information

In the following subsection, we analyze whether investors consider information on the sponsor's loss experience when they assess the risk associated with a CAT bond. For that purpose, a fixed effects model of the following form is introduced:

$$\widehat{premium}_{it} = \gamma' \hat{Y}_t + \delta' \hat{Z}_{it} + \hat{u}_{it}, \tag{7}$$

[23] In a robustness check, we estimated model (I.1) with an alternative specification of the "Experience" variable, where experience was measured in the same manner but also took into account whether a sponsor participated in the structuring and placement of another sponsor's bond. The modified version of this variable did not produce significantly different results from those of the original version.

The variables in this model are within transformed, that is, the hat notation indicates that the variables are expressed as deviations from their means. The fixed effects model has less restrictive assumptions than the random effects model. The estimators are consistent even if the explanatory variables are correlated with the unobservable bond-specific effect a_i in Equation (6) (Baltagi, 2013; Wooldridge, 2015).

The data set is limited to bonds of sponsors underwriting primary insurance policies in the US market and the time period between 2005 and 2016 because of data availability requirements. The models include year fixed effects and the interaction term "EL $\times$ Year" to capture all common evolutions of CAT bond premia over time. The results are shown in Table 5. All models contain the variables "TTM", "S&P500" and "Corp. Spread" as controls.[24] This set of variables explains almost 76 percent of variance in CAT bond premia over time. In model (II.2), the first extension of the benchmark model (II.1), we include the "Loss Ratio" variable and the interaction term "Trigger Indemnity $\times$ Loss Ratio" and we control for reinsurance coverage. As expected, the loss ratio is only significant for bonds with an indemnity trigger ($p < 5\%$), and, in accordance with the loss experience hypothesis (H5), investors demand higher risk premia if the sponsor had a higher loss ratio in the previous year. According to the estimated model, for bonds with an indemnity trigger, an increase in the loss ratio by 10 percentage points leads to an increase in the bond's premium by 15 bp. In model (II.3), a modified trigger variable is applied that equals one if the trigger is either indemnity based or hybrid. Thereby, we take into account that a hybrid CAT bond trigger can also be partly indemnity based. After this modification, the coefficient on the trigger variable decreases, but at the same time, the statistical significance increases ($p < 1\%$), indicating a stable effect. Finally, in model (II.4), we control for interaction terms with all of the major trigger types, introducing dummy variables for indemnity, industry index, modeled loss, and hybrid trigger mechanisms. The base category is formed by bonds with a parametric trigger. Each dummy variable is interacted with the loss ratio. In line with the results in model (II.3), we find a significant positive effect of the loss ratio on the premia of bonds with

[24] The variable "Reins. Index" is excluded from this analysis since it only varies by year and is therefore collinear to the year fixed effects.

indemnity triggers (16 bp premium increase for a loss ratio increase by 10 percentage points). The coefficient on bonds with hybrid trigger mechanisms is smaller and only marginally significant. The evidence obtained from models (II.1) to (II.4) also supports the trigger hypothesis (H4), under which we assumed premia to be higher for indemnity-triggered bonds, especially when previously experienced losses are also high.

Table 5: **Impact of Sponsor Loss Experience on Premia.**
This table reports fixed effects estimates of sponsor Loss Ratios on premia (in %). The base variable for trigger types in model (II.4) is Parametric. Standard errors are clustered by bonds and robust to heteroscedasticity. *p*-values are shown in parentheses. The symbols †, *, **, and *** indicate statistical significance at the 10%, 5%, 1%, and 0.1% levels, respectively.

	(II.1)	(II.2)	(II.3)	(II.4)
TTM	0.123	0.091	0.085	0.072
	(0.633)	(0.731)	(0.751)	(0.790)
Macroeconomic variables				
S&P500	0.002	0.001	0.002	0.002
	(0.826)	(0.900)	(0.821)	(0.826)
Corp. Credit Spread	0.240***	0.236***	0.235***	0.237***
	(0.000)	(0.000)	(0.000)	(0.000)
Exposure variables				
Loss Ratio		-0.002	-0.003	-0.004
		(0.415)	(0.328)	(0.343)
Reinsurance Ratio		0.007	0.005	0.007
		(0.675)	(0.752)	(0.673)
(Trigger Indemnity or Hybrid) × Loss Ratio			0.012**	
			(0.007)	
Trigger Indemnity × Loss Ratio		0.015*		0.016*
		(0.028)		(0.017)
Trigger Industry Index × Loss Ratio				0.001
				(0.705)
Trigger Modeled × Loss-Ratio				0.020
				(0.218)
Trigger Hybrid × Loss-Ratio				0.010†
				(0.087)
Constant	4.325*	4.398*	4.414*	4.412*
	(0.022)	(0.023)	(0.023)	(0.023)
Year fixed effects	yes	yes	yes	yes
EL × Year	yes	yes	yes	yes
Observations	841	841	841	841
Within-R^2	0.767	0.769	0.770	0.770
Adjusted within-R^2	0.760	0.761	0.762	0.762

4.3 Analysis of Macroeconomic and Event Variables

In this subsection, we apply the fixed effects model from Equation 7 to identify natural and economic events that affected the premia of CAT bonds. We consider hypothesis (H6) and analyze whether non-US events also have an influence on CAT bond premia, based on the Tohoku Earthquake. In hypothesis (H7), a possible premium-reducing effect of catastrophic events on the CAT bond market was assumed in the case that an event – although catastrophic – results in a low level of losses to CAT bonds. This hypothesis is tested on the basis of Hurricane Sandy. Finally, in hypothesis (H8), we stated that the non-occurrence of a catastrophic event might lead to decreasing premia on the CAT bond market. This assumption will be examined for the 2009 hurricane season. We assume that the observed events may cause changes in both the absolute premium level (change in the intercept) and the level of trust/mistrust in the EL (change in the coefficient on the EL). Although a catastrophic event may affect both the premium level and the multiple of the EL, we should find different effects for economic events such as the Lehman Brothers bankruptcy. For the latter event type, an increased EL-multiple caused by mistrust in reported ELs is implausible.[25] Besides the Lehman Brothers bankruptcy, the analyzed events are all related to the (non-) occurrence of natural catastrophes and not to economic developments. Therefore, a significant change in the EL-multiple for the respective events would support our event-related hypotheses. In addition to possible event-specific effects on the premium level and the EL-multiple, we further investigate the relationship between the events and the use of indemnity-based trigger mechanisms to substantiate the trigger hypothesis (H4).

In the first step, the three fixed effects models (III.1) to (III.3) are estimated, and the results are presented in Table 6 to evaluate the explanatory power of the event variables against a benchmark. Model (III.1) includes the time-variant bond-specific variable "TTM" and year fixed effects. This model has a within-R^2 of almost 43 percent. In model (III.2), the additional interaction terms "EL $\times$ Year" are included, which are jointly significant and increase the model's explanatory power to 49 percent of the variation over time. In model (III.3), two further groups of interaction terms account for differing effects in the dependence of the trigger mechanism: "Trigger Indemnity $\times$ Year" and "EL $\times$ Trigger Indemnity $\times$ Year". The inclusion of those additional groups of jointly significant interaction terms leads to a further increase of the within-R^2 to 52 percent.

[25] Hurricane Ike made landfall at approximately the time of the Lehman Brothers bankruptcy. This catastrophe could potentially also have affected premia on the CAT bond market. Consequently, the occurrence of Hurricane Ike could be a possible explanation for increased EL-multiples after the Lehman Brothers bankruptcy (Gürtler et al., 2016).

In the next step, we identify the events with the most significant impact on CAT bond premia by applying the method of panel threshold regression developed by Hansen (1999). A threshold model is based on the possibility of different slopes for values below and above a threshold. The optimal threshold value is obtained from the minimization of the sum of squared errors.[26] In this case, the threshold value corresponds to the time variable "Quarter". Following Hansen (1999), we differentiate between the quarters before and after the threshold quarter, apply the regression for every possible threshold quarter, and identify the quarter with the minimum sum of squared errors.

As we are interested in five events, that might have significantly affected CAT bond premia (see Section 3), the minimization procedure comprises five steps to verify whether the suggested events have the greatest explanatory power with regard to CAT bond premia. After each step, the variable for the threshold quarter that solves the minimization enters in the subsequent step. Hansen (1999) remarks that a small number of observations within a regime determined by the step-wise minimization is undesirable. We therefore establish the condition that two threshold quarters must be separated by at least a year.

The first step of the minimization is solved by the fourth quarter of 2008 (i.e., the "Lehman" variable). Interestingly, in the next minimization step, we identify the Hurricane Sandy (i.e., the first quarter of 2013) as the second event that had a strong effect on the CAT bond premia. Prior studies suggested that the 2005 hurricane season including Hurricanes Katrina, Rita, and Wilma, was the event with the most pronounced impact on the CAT bond market (Dieckmann, 2008; Ahrens et al., 2009; Gürtler et al., 2016). However, the occurrence of Sandy was not covered in the authors' data sets. In our opinion, a possible reason for Sandy contributing more explanatory power for the optimization in our data set might be the ILS market's size at the occurrence of the two events. As mentioned in Section 2, the outstanding volume in the ILS market more than doubled from 2006 to 2013. Therefore, the Sandy variable affects more observations in our data

[26] In Hansen (1999), the method is applied to a balanced panel $\{y_{it}, q_{it}, x_{it} : 1 \leq i \leq n, 1 \leq t \leq T\}$ based on the model equation $y_{it} = \mu_i + \beta_1 x_{it} I(q_{it} \leq \gamma) + \beta_2 x_{it} I(q_{it} > \gamma) + e_{it}$, with I being the indicator function. The threshold regression consists of two steps. First, the OLS slope coefficients $\beta(\gamma)$ are estimated for the dependence of γ. Second, the sum of squared errors is minimized with respect to γ, resulting in the optimal threshold γ^* and the corresponding slope parameters $\beta(\gamma^*)$.

set, which might, in turn, lead to greater explanatory power. The third minimization loop is solved by the first quarter of 2010. This point in time coincides with our "Season 2009" variable, so this result provides initial evidence for our no event hypothesis (H8).[27] The fourth minimization step results in the first quarter of 2006, which can be attributed to the 2005 hurricane season. Interestingly, the fifth step does not yield the Tohoku event, but rather yields the second quarter of 2015. However, we do not further analyze the effects of this threshold for three reasons. First, we do not observe an actual event that might have affected the CAT bond market at this point in time, so we are lacking an economic justification for establishing a threshold in the second quarter of 2015. Second, the event does not cause significant changes in the effects measured for the other four events, and, third, we do not want to needlessly boost model complexity.

Since none of the five minimization steps was solved by the "Tohoku" variable, we reject hypothesis (H6).[28] We cannot generalize this result for future non-US events, but at least we can conclude that the Tohoku Earthquake, which caused severe damages did not affect the CAT bond market. This result has two possible causes. First, even if a number of CAT bonds insure earthquake perils in Japan, US events – and among those mostly hurricanes – by far have the biggest market share.[29] Second, although the Tohoku earthquake caused considerable losses to the CAT bond market,[30] these losses might have been moderate compared to the losses incurred by the rest of the (re)insurance sector. This assumption is supported by the fact that most of the bonds distressed by the earthquake contained a second event cover and only a second catastrophic event could have caused losses to investors in these bonds.

Next, we analyze the events identified by the minimization procedure in more detail

[27] In fact, at approximately the same time, an earthquake occurred in Chile in February 2010 causing insured losses with a volume of 8 billion USD (Artemis, 2010). No CAT bond was insuring earthquake risks in Latin America at that time, so this earthquake is unlikely to be the reason for this result.

[28] The fact that the Tohoku Earthquake is not identified as a relevant event by the threshold regression method of Hansen (1999) implies that other events explain a larger share of variance in CAT bond premia over time. However, the Tohoku Earthquake might still have had a significant effect on CAT bond premia. In the context of the subsequently introduced models, we test for this possibility, and the results indicate that the Tohoku Earthquake's effect on CAT bond premia was insignificant.

[29] According to the summary statistics in our data set, 75 percent of the CAT bonds insure US perils, whereas only 18 percent insure perils in Japan.

[30] An example is the total default of the Munich Re bond Muteki with a volume of 300 million USD.

and replace the year dummies and interaction terms in models (III.1) to (III.3) with event variables. The resulting model (III.4) contains event variables instead of the set of year dummy variables, and model (III.5) additionally contains "EL × Event" interaction terms instead "EL × Year" interaction terms. In model (III.6) we additionally include the interaction term "Trigger Indemnity × Event" instead of the interaction term "Trigger Indemnity × Year" and we replace the term "EL × Trigger Indemnity × Year" in an analogous manner by "EL × Trigger Indemnity × Event". The results obtained with these three models can be found in Table 6. Interestingly, in terms of the within-R^2, the three models with event variables outperform their respective counterparts with year dummies, which leads to the conclusion that the event variables actually exhibit a significant effect on premia. In model (III.4), we find that all four dummy variables are statistically significant at the 0.1% level. The variables "Season 2005" and "Lehman" have positive influences on the risk premium of 181 bp and 406 bp respectively. On the contrary, the variable "Season 2009" has a negative effect on the level of risk premia amounting to 184 bp. As mentioned, a possible reason for this result could be the below-average losses from the 2009 hurricane season. This result is first evidence for the no event hypothesis (H8). However, considering the timing of this event and the negative coefficient, an alternative explanation for this result could be associated with the recovery after the financial crisis. A post-crisis reversion of CAT bond prices is supported by the literature on other asset classes (Schwert, 2011; Dick-Nielsen et al., 2012). Later on, we will analyze in more detail whether the measured threshold can more likely be assigned to the 2009 hurricane season or to a post-crisis market recovery. The "Sandy" variable also has a negative effect with a magnitude of 226 bp, which supports the market performance hypothesis (H7).

When we include the interaction terms "EL × Event", the absolute values of the dummy variable coefficients decrease. Nevertheless, all of the dummy variables remain statistically significant. Furthermore, we find that the interaction term 'EL × Season 2005' is significantly positive ($p < 5\%$) with a coefficient of 0.53, which provides initial evidence of investors mistrusting calculated ELs in the aftermath of the 2005 hurricane season. The interaction term "EL × Lehman" is insignificant, suggesting that the bankruptcy of

Lehman Brothers only led to an absolute increase in risk premia. For the variables "Sandy" and "Season 2009", the coefficients on the interaction term "EL $\times$ Event" are significantly negative at the 0.1 and 5% levels, respectively, suggesting that the EL-multiple fell by 0.85 after Sandy and by 0.34 after the 2009 hurricane season. The first result is consistent with our market performance hypothesis (H7) and indicates a reinforced trust in EL estimates. As the Lehman Brothers bankruptcy itself did not affect EL estimates, it would be surprising if a financial recovery after the crisis affected EL estimates. Therefore, the coefficient on the interaction term "EL $\times$ Season 2009" supports the no event hypothesis (H8).

In model (III.6), we introduce interaction terms of the types "Trigger Indemnity $\times$ Event" and "EL $\times$ Trigger Indemnity $\times$ Event". Among these, only the term "EL $\times$ Trigger Indemnity $\times$ Season 2005" was significantly positive ($p < 0.1\%$), with an effect size of 2.11. This result indicates an increased mistrust towards bonds with indemnity triggers after large loss events and confirms the trigger hypothesis (H4). Although the coefficients on most of the remaining variables are unaffected by the inclusion of the additional interaction terms, the term "EL $\times$ Season 2005" is no longer significant. Thus, the increase in EL-multiples after the 2005 hurricane season was restricted to bonds with indemnity triggers.[31]

In Table 7, the influence of the events is reviewed in more detail. Beginning with the results of Table 6, the fixed effects model (IV.1) includes the significant terms of models (III.5) and (III.6). In model (IV.2), we also include the macroeconomic variables introduced in Section 3. Model (IV.3) is used to test the existence of peril-specific reactions to the hurricane events "Season 2005", "Season 2009" and "Sandy". In model (IV.4), we analyze whether the event variables "Lehman" or "Season 2009" result in significant changes in the correlation between CAT bond and corporate credit spreads to rule out the possibility that the latter event was related to a post-crisis recovery.

[31] We also tested model (III.6) including the "Tohoku" variable as defined in Equation 4 and the interaction terms "EL $\times$ Tohoku", "Trigger Indemnity $\times$ Tohoku" and "EL $\times$ Trigger Indemnity $\times$ Tohoku" to evaluate whether these variables might have a significant effect on CAT bond premia, even if they explain only a small share of variance over time. The results indicate that none of the four variables has a significant effect.

Table 6: **Impact of Catastrophic Events on Premia – preliminary analysis.** This table reports fixed effects estimates of catastrophic events on premia (in %). Standard errors are clustered by bonds and robust to heteroscedasticity. p-values are shown in parentheses. The symbols †, *, **, and *** indicate statistical significance at the 10%, 5%, 1%, and 0.1% levels, respectively.

	(III.1)	(III.2)	(III.3)	(III.4)	(III.5)	(III.6)
TTM	0.029	-0.010	0.020	0.439***	0.432***	0.430***
	(0.856)	(0.950)	(0.902)	(0.000)	(0.000)	(0.000)
Event dummies						
Season 2005				1.814***	1.164***	1.279***
				(0.000)	(0.000)	(0.000)
Lehman				4.064***	3.712***	3.637***
				(0.000)	(0.000)	(0.000)
Season 2009				-1.839***	-1.264***	-1.213**
				(0.000)	(0.001)	(0.010)
Sandy				-2.263***	-0.574†	-0.720†
				(0.000)	(0.058)	(0.090)
Interaction effects						
EL × Season 2005					0.533*	0.251
					(0.047)	(0.276)
EL × Lehman					0.211	0.149
					(0.223)	(0.480)
EL × Season 2009					-0.343*	-0.330†
					(0.012)	(0.060)
EL × Sandy					-0.849***	-0.736**
					(0.000)	(0.007)
Trigger Indemnity × Season 2005						-1.049
						(0.417)
Trigger Indemnity × Lehman						0.445
						(0.534)
Trigger Indemnity × Season 2009						-0.257
						(0.670)
Trigger Indemnity × Sandy						0.322
						(0.577)
EL × Trigger Indemnity × Season 2005						2.111***
						(0.000)
EL × Trigger Indemnity × Lehman						0.221
						(0.504)
EL × Trigger Indemnity × Season 2009						-0.093
						(0.695)
EL × Trigger Indemnity × Sandy						-0.259
						(0.387)
Constant	7.143***	4.539**	4.109**	2.989***	2.674***	2.277***
	(0.000)	(0.003)	(0.004)	(0.000)	(0.000)	(0.000)
Year fixed effects	yes	yes	yes	no	no	no
EL × Year	no	yes	yes	no	no	no
Trigger Indemnity × Year	no	no	yes	no	no	no
EL × Trigger Indemnity × Year	no	no	yes	no	no	no
Observations	1951	1951	1951	1951	1951	1951
Within-R^2	0.428	0.491	0.520	0.488	0.522	0.538
Adjusted within-R^2	0.423	0.483	0.504	0.487	0.519	0.534

The results obtained in model (IV.1) largely correspond to the results from model (III.4), since the only change is the exclusion of the insignificant interaction terms. Among the macroeconomic variables included in model (IV.2), the variable “Corp. Spread” has a significantly positive influence ($p < 0.1\%$) on premia, and a one percentage point increase in the "Corp. Spread" leads to a 13 bp increase in CAT bond premia. This result reveals the dependence between the spreads of CAT bonds and corporate bonds. Furthermore, the relative change in the reinsurance market index and the premium share a strong positive relationship ($p < 0.1\%$). A relative increase in the "Reins. index" by 10-% increases CAT bond premia by 21 bp. The quarterly return of the S&P500 is insignificant, which might result from including the set of event variables. The "S&P500" and the "Reins. Index" variables do not show any cross-sectional variance, and a large share of the variance is already explained by the event variables.[32] After the inclusion of macroeconomic factors, the dummy variables "Season 2005" and "Sandy" are no longer significant. All of the other event-related terms remain significant. Hence, after controlling for the reinsurance price level, the effect of the two hurricane events "Season 2005" and "Sandy" is restricted to that of the trust/mistrust in EL estimates. The relevance of the correlation of CAT bond premia with reinsurance prices is also shown by the decreasing coefficient on the term "EL $\times$ Season 2009".

In model (IV.3), we introduce additional interaction terms of the types "Event $\times$ Hurricane" and "EL $\times$ Event $\times$ Hurricane" to test whether the premium adjustment after catastrophic events is stronger for hurricane bonds than for other bonds. For the 2005 hurricane season, we observe a marginally significant positive effect ($p < 10\%$) of the EL interaction term, with a magnitude of 0.43. Compared to model (IV.2), the effect of the 2005 hurricane season on the EL-multiple of bonds with an indemnity trigger increases to 2.11 ($p < 0.1\%$). Surprisingly, the effect on the EL-multiple for hurricane bonds is negative with a magnitude of 1.24 ($p < 5\%$), whereas the absolute premium level for hurricane bonds increased by 214 bp ($p < 5\%$). It therefore seems that the 2005 hurricane season caused an absolute increase of the premium level for hurricane bonds, whereas the EL-multiple increased only for hurricane bonds with an indemnity trigger. After this devastating event, investor preferences possibly tended toward alternative trigger

[32] On the contrary, the third macroeconomic variable, the "Corp. Spread" varies over time and rating classes.

mechanisms.[33] Distinct effects are measured for Hurricane Sandy. This event resulted in a reduction of the EL-multiple for all CAT bonds ($p < 10\%$) by 0.43 as well as in an additional reduction of the EL-multiple of hurricane bonds ($p < 5\%$) by 0.46. Sandy also led to a weakly statistically significant decrease in the absolute premium level for hurricane bonds ($p < 10\ \%$) by 89 bp. Consequently, the robust performance of the CAT bond market after Sandy increased investors' trust in EL estimates on the CAT bond market, and most of this growth in trust can be assigned to hurricane bonds. Finally, investors' perception of the overall level of risk in the CAT bond market decreased in the segment of hurricane bonds. The mentioned effects all support the market performance hypothesis (H7). The coefficient on the "Lehman" variable remains significant, although the magnitude decreases to 296 bp ($p < 0.1\%$) after the inclusion of macroeconomic controls. For the 2009 hurricane season, we find that the event variable itself is no longer significant after including the above-mentioned set of interaction terms. The effect of the term "EL $\times$ Season 2009" is still significant and negative ($p < 5\ \%$), with a magnitude of 0.35, and we measure an additional marginally significant reduction in the EL-multiple for hurricane bonds of 0.28 ($p < 10\%$). Furthermore, the absolute premium level for hurricane bonds ($p < 5\%$) decreases by 121 bp. These results indicate that the event observed in the first quarter of 2010 is a consequence of below-average hurricane losses in 2009 rather than of a recovery from the Lehman Brothers bankruptcy, and, thus, these results support the no event hypothesis (H8).[34]

[33] If we observe the aggregate effect of the terms related to the 2005 hurricane season at the level of the median EL, the largest premium increase is found for hurricane bonds with an indemnity trigger, followed by indemnity triggered bonds insuring perils other than hurricanes. The third largest effect is found for hurricane bonds with alternative trigger types, and the smallest premium increase is measured for non-hurricane bonds with alternative trigger types. The negative coefficient on the term "EL $\times$ Season 2005 $\times$ Hurricane" shifts this ranking for higher ELs and the bonds insuring hurricane perils exhibit smaller premium increases than those of their respective counterparts.

[34] Although it is difficult to grasp, we identify another possible reason for this result related to Hurricane Ike. To our knowledge, the hurricane affected the two bonds Nelson Re Ltd. and Blue Coast Ltd. For the bond Nelson Re Ltd., which used an indemnity trigger, the possibility of losses from Ike was first reported in March 2009 (Artemis, 2009b). In November 2009, the rating agency Moody's downgraded one tranche of the bond in light of possible losses to investors (Artemis, 2009a). Later, questions incurred related to the policies underlying Nelson Re Ltd., and, in September 2011, Moody's did not have any proof of losses to policyholders (Artemis, 2011b). Afterwards, the sponsor Glacier Re tried to pursue its possible claim on the principal in a lengthy arbitration process that was finally withdrawn in February 2013 (Artemis, 2013a). In March 2009, S&P downgraded the bond Blue Coast Ltd. (index trigger) because Hurricane Ike had already eroded more than 40 percent of the bond's retention, and, therefore, the attachment probability had increased. Taking into account this information, the result

In model (IV.4), interaction terms between the variable "Corp. Spread" and the two variables "Lehman" and "Season 2009" are included. The interaction term "Corp. Spread × Lehman" is statistically significant at the 5% level and suggests that during the Lehman period, a one percentage point increase in the Corp. Spread led to an additional increase in CAT bond spreads by 8 bp. This result shows that after the Lehman Brothers bankruptcy, the correlation between CAT bond premia and corporate bond spreads increased. On the contrary, the term "Corp. Spread × Season 2009" is insignificant, which supports the no event hypothesis (H8). Hence, it is unlikely that the downward shift of CAT bond premia in the beginning of 2010 is attributable to a post-crisis recovery.

5 Conclusions

This study examines the influence of sponsor characteristics as well as catastrophic and economic events on CAT bond premia. A summary of all of the results is depicted in Table 8.

The analysis of sponsor-specific variables reveals that the premium is influenced by the diversification of a bond's sponsor. As expected in the rating hypothesis (H2), investors demand a higher premium from sponsors with a speculative grade or without a rating. The participation of both the sponsor and another agent in the structuring and placement reduces the premium level. This finding supports the vertical integration hypothesis (H3). The application of indemnity triggers seems to have a significant positive effect on premia, which is in line with the trigger hypothesis (H4).

We conduct the first analysis of CAT bond premia that utilizes data on bond sponsors' actual loss experience. The one-year-lagged loss ratio (in business lines affected by natural catastrophes) of companies that use CAT bonds with an indemnity trigger has a positive significant effect on premia. For bonds with a hybrid trigger mechanism, we also identify a positive and (marginally) significant effect, although it is smaller in magnitude. Therefore, as we expected in the loss experience hypothesis (H5), investors actively take into account the losses incurred by CAT bond sponsors beyond the EL estimates. In addition,

for the "Season 2009" variable could indicate that in the beginning of 2010 – after a below average hurricane season in 2009 – investors were confident that for both Nelson Re Ltd. and Blue Coast Ltd., principal losses were unlikely, which, in combination with the nonexistent hurricane losses in 2009 led to the investigated effects.

Table 7: **Impact of Catastrophic Events on Premia – Main Analysis.**
This table reports fixed effects estimates of catastrophic events on premia (in %). Standard errors are clustered by bonds and robust to heteroscedasticity. *p*-values are shown in parentheses. The symbols †, *, **, and *** indicate statistical significance at the 10%, 5%, 1%, and 0.1% levels, respectively.

	(IV.1)	(IV.2)	(IV.3)	(IV.4)
TTM	0.433***	0.304***	0.301***	0.294***
	(0.000)	(0.000)	(0.000)	(0.000)
Macroeconomic variables				
Reins. Index		0.021***	0.021***	0.022***
		(0.000)	(0.000)	(0.000)
S&P500		0.003	0.002	0.004
		(0.476)	(0.598)	(0.349)
Corp. Credit Spread		0.130***	0.129***	0.102***
		(0.000)	(0.000)	(0.000)
Event dummies				
Season 2005	1.216***	0.441	0.049	0.012
	(0.000)	(0.212)	(0.893)	(0.974)
Lehman	4.050***	2.989***	2.963***	2.202***
	(0.000)	(0.000)	(0.000)	(0.000)
Season 2009	-1.373***	-0.803*	-0.378	0.133
	(0.000)	(0.015)	(0.229)	(0.806)
Sandy	-0.572†	-0.473	-0.180	-0.187
	(0.058)	(0.115)	(0.596)	(0.578)
Interaction effects with Season 2005, Season 2009 and Sandy				
EL × Season 2005	0.281	0.262	0.428†	0.424†
	(0.217)	(0.245)	(0.058)	(0.061)
EL × Sandy	-0.849***	-0.853***	-0.364*	-0.366*
	(0.000)	(0.000)	(0.018)	(0.017)
EL × Season 2009	-0.279*	-0.281*	-0.347**	-0.332**
	(0.016)	(0.012)	(0.001)	(0.003)
EL × Trigger Indemnity × Season 2005	1.672***	1.694***	2.113***	2.096***
	(0.000)	(0.000)	(0.000)	(0.000)
Season 2005 × Hurricane			2.141*	2.132*
			(0.027)	(0.027)
Season 2009 × Hurricane			-1.207**	-1.144*
			(0.009)	(0.010)
Sandy × Hurricane			-0.890†	-0.895†
			(0.051)	(0.050)
EL × Season 2005 × Hurricane			-1.239*	-1.220*
			(0.015)	(0.016)
EL × Season 2009 × Hurricane			0.277†	0.254
			(0.094)	(0.136)
EL × Sandy × Hurricane			-0.459*	-0.457†
			(0.050)	(0.050)
Interaction effects with Lehman				
Corp. Credit Spread × Lehman				0.082*
				(0.036)
Corp. Credit Spread × Season 2009				-0.054
				(0.357)
Constant	2.246***	2.750***	2.858***	3.067***
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	1951	1951	1951	1951
Within-R^2	0.533	0.562	0.580	0.582
Adjusted within-R^2	0.531	0.559	0.576	0.578

Table 8: **Summary of Results.**
This table summarizes the hypotheses and results regarding the positive or negative dependence of CAT bond premia.

Hypothesis	Variable	Expected sign	Result
H1: Experience and diversification hypothesis	Experience/Diversification	–/–	✓
H2: Rating hypothesis	Rating grade	–	✓
H3: Vertical integration hypothesis	Sponsor and Other in Struct. and Plcmt.	–	✓
H4: Trigger hypothesis	Trigger Ind./Trigger Ind. × Season 2005	+/+	✓
H5: Loss experience hypothesis	(Trigger Indemnity or Hybrid) × Loss Ratio	+	✓
H6: Tohoku hypothesis	Tohoku	+	✗
H7: Market performance hypothesis	EL×Sandy/Sandy×Hurricane	–/–	✓
H8: No event hypothesis	EL×Season 2009/Season 2009×Hurricane	–/–	✓

hypothesis (H4) is supported by this results, as it indicates that the combination of high sponsor-specific loss levels and the use of indemnity triggers increases CAT bond premia.

In the analysis of the impact of catastrophic and economic events on premia, we identify four major incidents that jointly explain almost 60 percent of the variation in CAT bond premia over time. Those events are the 2005 and 2009 hurricane seasons, the bankruptcy of the investment bank Lehman Brothers, and Hurricane Sandy. In the analysis of the 2005 hurricane season, we show that the price reaction to this event differed by trigger and peril type and that premium increases were smaller for bonds with non-indemnity triggers. Consequently, investors adjusted their loss expectations in a sophisticated manner and thereby penalized bonds with indemnity triggers, which supports the trigger hypothesis (H4). On the contrary, after Hurricane Sandy, the CAT bond market experienced a decrease in the EL-multiple, and the largest share of this decrease can again be assigned to hurricane bonds. Furthermore, the absolute premium level of hurricane bonds decreased. This result provides support for the market performance hypothesis (H7). The findings resulting from the analysis of the 2009 hurricane season, which passed without major losses, reveal a decrease in the relative premium level on the overall CAT bond market and in the absolute premium level for hurricane bonds. Moreover, the analysis indicates that it is unlikely that this event was related to a post-crisis recovery and, therefore, this finding supports our no event hypothesis (H8). We fail to identify any effect of a non-US event on the CAT bond market, and, consequently, we have to reject the Tohoku hypothesis (H6).

The results on the Lehman Brothers bankruptcy reveal a strong impact of the financial crisis on the level of risk premia for CAT bonds and increased the correlation between CAT bond premia and corporate credit spreads. Our analysis further implies that Hurricane Ike most likely did not cause the reaction of CAT bond premia at this point in time.

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