

# Cat Bond Spread in the Primary Market:

## The Main Drivers

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### Abstract

Catastrophic (cat) bond is a very recent security, which enables insurance and reinsurance companies to transfer risk to the capital markets. In this study we aim to determine the main drivers of the cat bond spread at issuance. We gathered all the information on cat bonds from December 1996 to March 2015, the largest data sample to date with 589 cat bond tranches. We find evidence that (1) expected loss is the main driver of cat bond spread, and (2) that other factors such as peak territory, reinsurance cycle, corporate bonds spread and sponsor have also a great impact.

Supervisor: Professor José Faias

*“Simply put, (re)insurance is the sales of promises. The customer pays money now. The insurer promises to pay money in the future should certain unwanted events occur.”*

Warren Buffett

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## 1. Introduction

We are facing drastic changes in regards to global warming and natural disasters, the frequency and severity are increasing and the predictability reducing, according to Plenum Insurance Liked Capital (2012) 905 natural catastrophe events occurred across the globe. Hence, the need to purchase insurance is increasing, and the need for insurers and reinsurers to purchase additional protection as well. Nowadays, some catastrophe areas have high density of population which increases the degree of loss. Moreover, the more frequent the catastrophe is, the higher is the level of perceived risk leading to more insurance purchases by the population and consequently a higher exposure for insurers. The increase in insurers' exposure will result in a higher catastrophe (cat) bond demand (Ahrens et al. 2009). Hence, the market for cat bonds has a high growth potential.

This paper analyzes the cat bond main characteristics: expected loss, size, term, trigger type, peril covered, sponsor and rating. Accordingly, we aim to determine the main drivers of cat bond spread in the primary market. In order to identify the determinants we introduce a multifactor model, which controls for the main characteristics of cat bonds such as trigger, territory, peril, size, term, expected loss, rating, sponsor, reinsurance cycle, and corporate bonds spread, we also add seasonality to the analysis. Our work contribution by (1) showing that expected loss is the main driver of the cat bond spread in a cross-section and time-series analysis, (2) finding that besides expected loss there are other cat bond spread drivers at issuance, (3) collecting the largest cat bond sample to date, December 1996 to March 2015, totaling 589 cat bond tranches.

The results we obtain from the multifactor model confirm that expected loss is the main driver of cat bond spread and there are other five drivers which have explanatory value for the cat bond spread at issuance. We find that larger issues are reflected into lower spreads, which is also confirmed for the term. In contrast it is found that peak territories lead to larger spreads. The additional factors of cat bond spread, reinsurance cycle, investment grade, sponsor and BB corporate bond spread, are also found to be influential.

Furthermore, from these results the six main drivers are identified and an econometric model construct based on expected loss, peak territory, sponsor, reinsurance cycle, investment grade and corporate bond spread. The findings are in line with the previous, and this model has a better explanation power than the previous. Overall, expected loss is confirmed to be the main

driver of cat bond spread at the time of issuance. Nevertheless, other factors are proven to also influence the spread at issuance.

Moreover, the market for cat bonds is of recent existence, with its first issue in the mid-1990s. Following Hurricane Andrew, in 1992, that resulted in losses of around 30 billion US dollars, the need to hedge the risk of natural disasters increased. Consequently, in 1992 the first catastrophe hedging contracts were created by the Chicago Board of Trade (CBOT). These contracts were call options spreads, however those lacked trading volume and were withdrawn (Cummins, 2012). Years later, catastrophe bonds were issued and in 1997 the first successful cat bond by Swiss Re, covering earthquake losses (Vaugirard, 2002).

The main purpose of cat bonds is to offer further risk-bearing capacity (Cummins, 2008). Hence, cat bonds are securities that enable the transfer of natural disasters risk to the capital markets. Investors are paid coupons except if an event occurs, if the event occurs the reinsurer is paid to cover its claims. This security is low correlated with the market and enables for portfolio diversification. Moreover, cat bonds are of highly significance in alternative risk transfer (ART) and the understanding of suitable pricing model is important (Galeotti et al., 2013).

The empirical research on cat bonds valuation is still very limited regardless of the growth in the market. The main reason for the lack of empirical research is the scarcity of public available information and the difficulty of collecting the available information. The literature available today is mainly focus on cat bond equilibrium models like Cox and Pedersen (2000) combine the estimated provability of catastrophic event with a cat bond price term structure model. Moreover, Egmai and Young (2008) study the difference in prices of each cat bond tranches, the main findings are that the seniority tranches have investment grades and priority payment, while junior tranches have larger coupon to compensate the speculative rating and consequently higher risk. On the other hand, contingent claim studies by Lee and Yu (2007) to the factors influencing default risk in bond issuance, while Jarrow (2010) base its cat bond valuation  $x$  on the reduced form models for the credit derivatives pricing.

In the primary market Lane (2000) fits a power function to the probability of first loss and the conditional expected loss. Years later Lane and Mahul (2008) with 250 cat bonds base on a linear model find that the risk prices are a function of the expected loss, peril, reinsurance cycle and rating. Lei et al. (2008) similarly with a linear model include cat bonds detailed characteristics such trigger type, size, maturity and rating in the study. Moreover,

Papachristou (2009) using a generalized additive model studies the risk premium factors. Bodoff and Gan (2009) combining expected loss, peril and territory construct a pricing model. Whereas Galeotti et al. (2013) apply different models to compute premiums and assess its fit. Econometric approaches empirical studies are not very popular in the field, however its specifications may help to determine the major drivers of cat bond pricing. Ahrens et al. (2009) perform an econometric pricing analysis; Bayesian estimation technique, on cat bonds during the Hurricane season of 2005 based on Lane (2000) model, and find that there is an increase from the severity component of the spread. Braun (2014) enlarges the data sample in study and constructs a multifactor model as well as an econometric pricing model to evaluate the cat bond pricing determinants. Overall, all these previous studies are done under small data samples and one or two factor models.

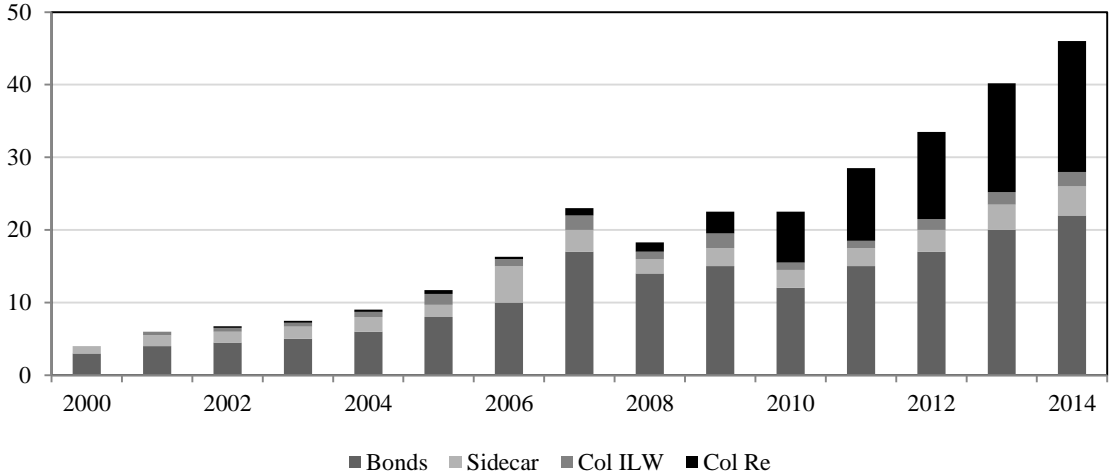
In the following section we give a deeper analysis and explanation on the primary market for cat bonds, the structure and main characteristics of cat bonds such as trigger, territory, sponsor and rating. In Section 3 the data is described, after in Section 4 the pricing determinants for cat bond spread are explained and the results analyzed. Further in Section 5 a robustness check with an in sample fit is computed and the findings described. In Section 6 the out-of-sample performance is detailed. Lastly in Section 7 the main conclusions of this work are drawn.

## **2. Catastrophe Bond in the Primary Market**

The Alternative Risk Transfer (ART) market has witnessed a fast pace development in the last decade, due to the increase in extreme loss risk caused by natural catastrophes, a result of climate change and the concentration of value (Gazert et al, 2014). ART can be seen as a hedging technique used by insurance and reinsurance companies to transfer risk to a third party or to the capital markets, in exchange with the transaction receive protection. Without insurance and reinsurance companies individuals and corporations are highly exposure to catastrophic events (Froot, 1999). “A risk is a risk, in whatever market it appears” as stated by Lane (2000), enhancing the need to buy protection not only by individuals and corporations but also by insurance and reinsurance companies. The later need funds for its reserves and to pay its claims, therefore in the mid-1990 with the introduction of an Insurance Liked Securities (ILS), known as cat bond, enabled the insurance and reinsurance industry to transfer risks to the capital market (Lane and Mahul, 2008). Cat bonds are of highly

importance because with them insurance and reinsurance access the capital markets which provides the capacity for its markets expanding the risk-bearing capacity (Cummins, 2008).

ILS, besides cat bonds, can have the form of a contingent capital, cat swaps, cat options, sidecars, collateralized quota shares and industry loss warranties (Cummins and Trainar, 2009). Figure 1 exhibits the market evolution of collateralized and bonds reinsurance. It shows the market for investors in reinsurance through non-equity involvements is increasing. From 2000 to 2014 the market sharply grown, for instance from 2013 to 2014 the market increased by more than 18%. Bonds and Collateralized Reinsurance are dominants in the market and maintain a high growth. Overall the largest growth witness was by Collateralized Reinsurance. Nevertheless, one can infer that the market is of high potential specially if accounting for the increase in natural disasters.

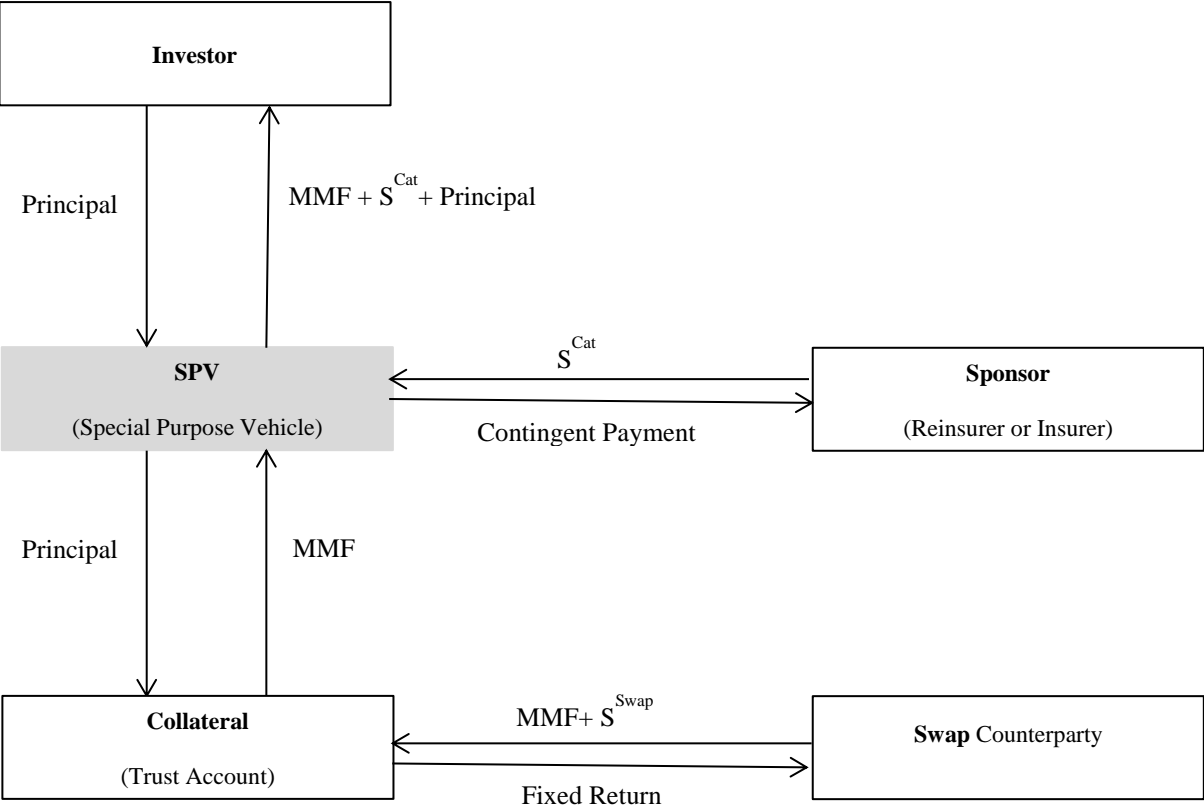


**Figure 1:** The Market Development for Collateralized and Bonds (AON Benfield, 2014)

This figure shows the evolution of the non-traditional reinsurance market, from 2000 to September 2014. The non-traditional forms of reinsurance present are: Collateralized Reinsurance (Col Re), Collateralized Industry-Loss Warrants (Col ILW), Sidecars and cat bonds (Bonds).

A cat bond typical transaction, as depicted in Figure 2, is initiated by a sponsor who constructs a special purpose vehicle (SPV) (Cummins and Trainar, 2009) that sells protection to the sponsor for natural disasters losses. The SPV receives premium from the sponsor as an exchange for coverage. In order to finance the risk incurred by selling protection, the SPV sells securities to investors and receives a principal amount in return. The proceeds from the sale are deposited in a trust account and invested in safe securities (e.g.: Treasury bonds or AAA corporate bonds) (Lakdawalla and Zanjani, 2012). Then the fixed returns on the trust account securities are swapped for the floating returns based on the London Interbank Offered Rate (LIBOR). The swap helps the sponsor and the investor to protect from interest rate risk

and default risk (Cummins, 2008). However, after the default of the Lehman Brothers the Swap Counterparty part of the transaction is eliminated. The investors are thus promised a coupon payment for bearing the risk. If an event occurs before maturity which meets the trigger conditions in the reinsurance contract, (1) the SPV will liquidate the collateral required to make the payment and reimburse the sponsor, who will have to pay the claims arising from the event. (2) The investors may lose part or their entire principal. In case of no event occurring the collateral is liquidated at the end of the term and investors will receive the coupon plus a spread ( $S^{Cat}$ ), and the principal (Braun, 2014).



**Figure 2:** Typical Structure of a Cat Bond Transaction

This figure shows an example of a typical pre-crisis and Lehman Brothers default structure of a cat bond transaction. Where, MMF stands for Money Market Fund Returns and  $S^{Cat}$  is the Cat Bond Spread (Insurance Premium),  $S^{Swap}$  is the total return swap spread.

Cat bonds are meant to cover specific territories in which a catastrophic event is highly probable to occur. The territory is defined by country (e.g.; Japan), region (e.g. Caribbean) or state (e.g.: California). In addition, catastrophe risks are events that may cause financial and economic losses, hard to predict and usually infrequent to happen, these risks include earthquake and wind storms (e.g.: hurricanes, tornadoes, typhoons, and cyclone) (Lee and Yu, 2007). A cat bond can have a single or multi-perils. There are several groupings of peril and

territories. The most common are Europe x Wind, Japan x Earthquake, U.S. x Wind and U.S. x Earthquake (AON Benfield, 2011).

Each cat bond payout is defined by a trigger mechanism. The trigger choice involves a trade-off between basis risk and transparency (Swiss Re, 2009). The modeled loss triggers is grounded on modeling software, whereas the parametric trigger evaluates the magnitude of the loss with a physical measure (natural Hazard). The industry loss is based on the insurance industry loss when it hits a certain level. The index trigger uses a specified index (Galeotti et al., 2013). The indemnity trigger is based on the actual losses of the sponsor, and is usually associated with higher prices (Cummins and Weiss, 2009). As well as with no basis risk for the sponsor and asymmetric information which results in an increase in moral hazard, since the sponsor might have an incentive to reduce its protection measures in detriment to the investors (Braun, 2014). The moral hazard can be reduced by the adoption of no-indemnity triggers; however it introduces basis risk to the sponsor (Cummins et al., 2004). Cat bonds can also be a combination of multi-trigger types.

Investors perceive cat bonds as an attractive investment because those are fully collateralized, thus eliminate credit risk exposure (Cummins, 2008). It provides diversification because the returns have low correlation with returns from securities markets (Litzenberger et al., 1996). The main explanation for the low correlation is that natural events are independent from capital markets. Nevertheless, the financial crises and U.S. hurricanes question this assumption (Gurtler et al., 2014). Similarly cat bonds play an important role in risk management (Hagendorff et al., 2014).

Moreover, specialized firms as RMS, AIR and EQECAT are responsible for the catastrophe risk analysis and qualifying the catastrophe event objectively. Through complex scientific models to access based on the property values and insurance contracts the degree of loss incurred in financial terms. This analysis requires risk metrics such as expected loss, probability of exhaustion and probability of first loss. The rating of each cat bond tranche is based on the value of expected loss, the higher expected loss the lower the rating the agency gives the bond.

In Table 1, an example of cat bond detailed information is presented. East Lane IV Ltd., Series 2011-1, is issued by Chubb Group, an American Insurance company, in March 2011 in the Cayman Islands. The risk modelling is computed by AIR Worldwide. The notes are

covering losses from hurricanes, winter storms, earthquakes and severe thunderstorms in the U.S., meaning this is a multi-peril cat bond for the U.S. In addition, East Lane IV Ltd. has an indemnity trigger, meaning triggered by the actual losses of Chubb Group. This structured bond is issued in two separate notes or tranches with different maturity, sizes and rating. The tranches have different seniority, size, payment schedules and rating. The tranches characterize the hierarchy payment, where senior tranches are less risky and have priority on claims payment (BMA, 2014). East Lane IV senior tranche, issued size of 225 million dollars, is the class A, rated BB+ due to its expected loss 0.92%, and spreads 5.75% over LIBOR, and has a term of 3 years. The junior tranche is classified with a lower rating due to its higher expected loss, BB and 1.20% respectively. It spreads 6.65% higher value than the senior tranches since investors demand a greater reward for bearing higher risk. Usually junior tranches have speculative grades, consequently require larger compensation (Egmai and Young, 2008). The junior tranche is issued for 205 million dollars and matures four years after issue. Both tranches pay coupon quarterly. The cat bond tranches can be trigger by any of the perils covered that generates losses greater than 3 billion dollars for class A and 2.15 billion for class B, exhaustion amounts are for class A 3.25 billion dollars and 2.45 billion dollars for class B (S&P, 2011). Class B tranche has the lower trigger attachment point and thus it is easily triggered.

<b>Issuer</b>	<b>East Lane Re IV Ltd. (Series 2011-1)</b>	
Sponsor	Chubb Group	
Structuring Agents	Deutsche Bank Securities & Goldman Sachs are structuring agents and book-runners.	
Risk Modelling	AIR Worldwide.	
Risks / Perils covered	U.S. hurricane, U.S. earthquake, U.S. severe thunderstorm, U.S. winter storm	
Trigger Type	Indemnity	
Class	A	B
Issue Date	Mar-11	Mar-11
Maturity	Mar-14	Mar-15
Size (\$M)	225.00	250.00
Rating	BB+	BB
EL	0.92 %	1.20%
Exhaustion P.	0.89%	1.13%
Spread	5.75%	6.65%

**Table 1:** East Lane Re IV Ltd. (Series 2011-1)

This table shows the main classification categories of a cat bond at issuance. EL stands for expected loss, Exhaustion Probability (Exhaustion P.) and the rating are given by Standard & Poor's based on the risk modelling losses calculated by AIR.

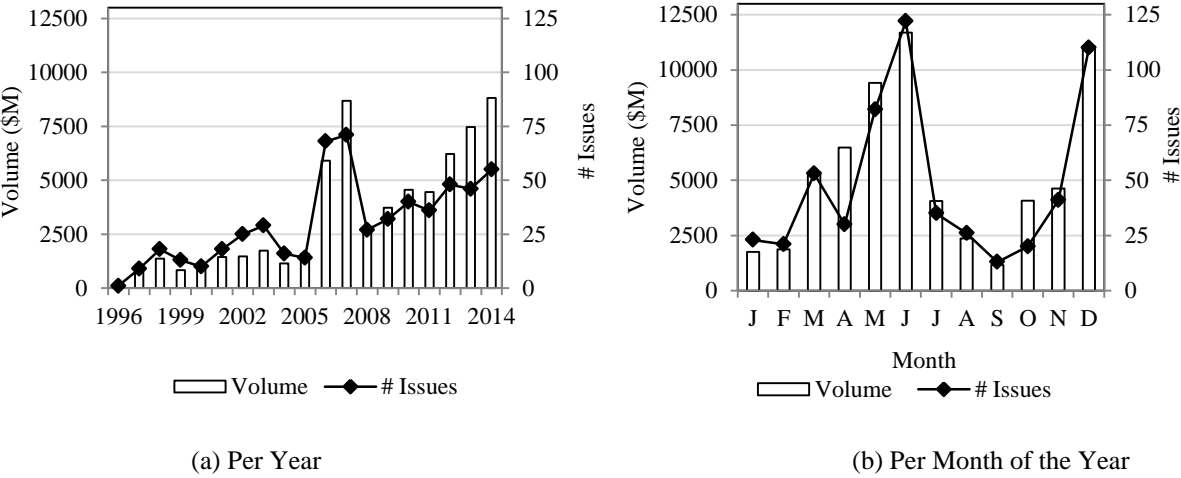
### 3. Data

The cat bond is a recent security in the market, even though it has a secondary market; this one is still in development. Thus, there is few publicly available transaction data, which represents a difficulty for empirical research. Consequently, diverse data sources are used to overcome this obstacle, including Thomson Reuters, Trade Notes by Lane Financial LLC, Artemis Deal Directory, Market Research and Annual Reports from Swiss Re, Munich Re, Aon Benfield, Guy Carpenter and Willis Re. The data is hand collected, clean and sorted. Cat bonds from December 1996 to March 2015 are gathered, accounting for the largest sample to date, 589 cat bond tranches issued in the period. For which we gather detailed information on spread, probability of first loss, conditional expected loss and expected loss, as well as issue date, term, size (in USD), cover territory, trigger type, sponsor, reference peril and rating. In this study cat bonds covering medical benefit claim levels, embedded value securitization of life insurance mortality and lapse risk, lottery winning, extreme mortality, longevity risk, motor policies, credit reinsurance, and event cancelation risk are not considered, which represents around 2% of the cat bond market.

As mentioned previously, cat bonds appeal to institutional investors because of its low correlation with the market (Cummins and Trainar, 2009). Accordingly, this financial instrument is growing and the number of issues rose in the period 2005 to 2007. However in 2005 a decrease in the number of issues can be interpreted by the hurricane Katrina in the U.S. Later it was highly affected by the 2008 financial crisis. This event result contradicts the fact that cat bonds are low correlated with financial risk, meaning that cat bonds should have resisted the crisis (Cummins and Trainar, 2009). In addition, with the default of Lehman Brothers four cat bonds defaulted and incurred in considerable losses. However, its tendency shifts and starts to increase from 2009 onwards, a result of investors regaining confidence in the market. Nevertheless, in 2011, a small decrease in volume and number of issues was a consequence of the Earthquake Tohoku in Japan. Nowadays, the primary market for cat bonds is above its pre-crisis size, and with potential for growing. This behavior is shown in Figure 3 (a), the market size of the primary market for cat bonds and the number of transaction issued per year, from December 1996 to December 2014.

In Figure 3 (b) the number of transactions per calendar month and respective issuance volume are illustrated. In the second and fourth quarter of the year the greater number and volume of transactions occur, which is seen as an anticipation of the hurricane season and the need for

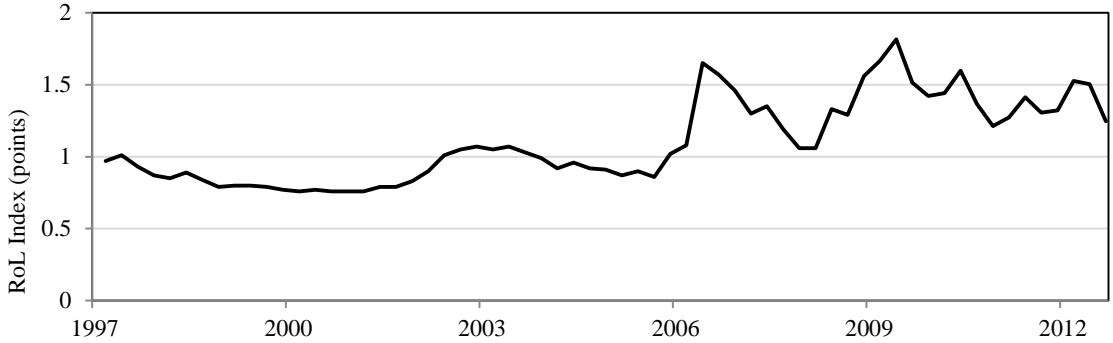
rebalance sponsors risk situation before the financial statements being prepared that result into a higher demand for coverage..



**Figure 3:** Primary Market Cat Bond Issuance History

This figure shows the cat bond issuance historical behavior from December 1996 to December 2014, accounting for a total of 576 cat bonds tranches. Figure 3 (a) displays yearly number of transactions (# of Issues) and U.S. Million dollars issuance volumes (Volume \$M), whereas Figure 3 (b) displays the same information subsampled by months.

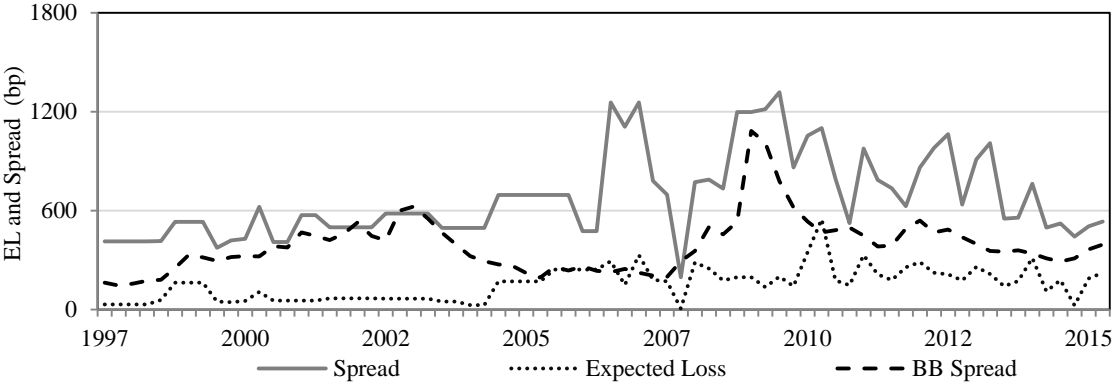
Furthermore, data regarding the cyclical influencing factors of cat bond spread is needed for the study. Therefore, the Lane Financial LLCC Synthetic Rate on Line Index (RoL), on a quarterly basis, is gathered. We combine based on Lane and Mahul (2008) the RoL, from Thomson Reuters, and Lane Financial Long Term Index of Catastrophe Reinsurance Prices, from Lane and Mahul (2008). However, there is only data available until the end of 2012 for both of these indices. In Figure 4 RoL is plotted and we can see a hard market from 2006 to today, which is indicated by values above one, for RoL.



**Figure 4:** Synthetic Rate on Line Index Historical Behavior

This figure shows the Lane Financial LLC Synthetic Rate on Line Index (RoL Index), in points, constructed as a combination of Lane Financial Long Term Index of Catastrophe Reinsurance and RoL.

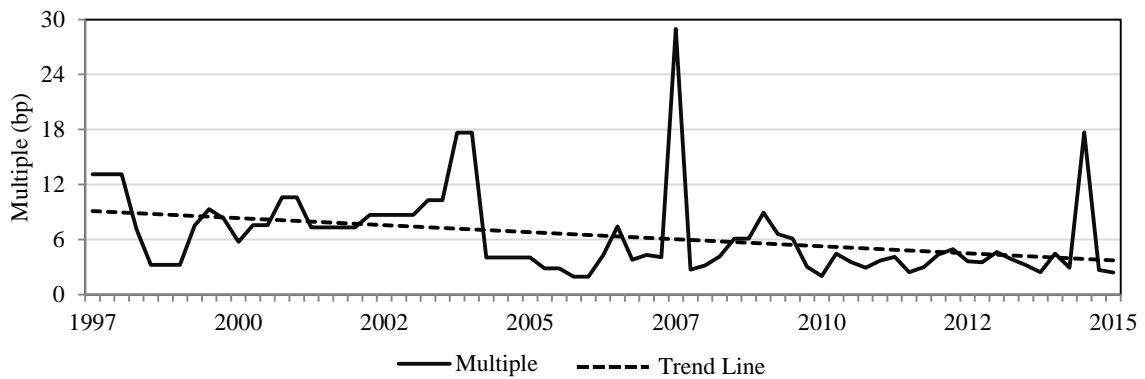
Moreover, the performance of the catastrophic risk premium from December 1996 to March 2015 is studied by averaging expected loss and spread across all tranches of issued cat bonds in the same quarter. In addition, to access corporate bond spread the Bank of America Merrill Lynch U.S. High Yield BB Option-Adjusted Spread (BB spread) is collected on a monthly basis from January 1997 to March 2015. In Figure 5 the index is plotted as a comparable measure, since most of cat bonds are rated BB. Also, in Figure 5 it is observable in 2005 a peak result from the Hurricane Katrina and in 2008 consequence of Lehman Brothers default, translated into larger cat bonds spread while expected loss keep a constant behavior throughout the period. In the sample the quarterly time series mean for expected loss is 154.94 basis points (bp), 670.80 bp for cat bond spread and 385.47 bp for BB spread. Over the period in analysis investors are compensated on average with a risk premium of 515.86 bp above expected loss and compared to corporate debt 282.43 bp of excess spread. The spread in cat bond market is substantially higher than in corporate debt market, which can be explained by the lower level of liquidity and higher complexity and the source of risk associated with cat bonds (Swiss Re, 2006).



**Figure 5:** Average Expected Loss and Spread Performance

This figure displays the performance of cat bond spread, expected loss (EL) and BB spread was added as a comparison measure, since the majority of cat bonds are rated at the same level. The time series was a result of averaging the variables across all cat bond tranches issued in the same quarter, in basis points (bp). In the quarters where no cat bond was issued the value of the previous quarter was adopted. The data is relevant to the period from December 1996 to March 2015.

The multiple of spread over expected loss is plotted in Figure 6. The observed trend is downward and linked to a high level of volatility. Quarterly time series mean of the multiple is 6.51 and for the post-crisis period 4.49. The post-crisis multiple value falls into the interval 3.00 to 5.00 described by Cummins and Weiss (2009) leading to the assumption that cat bonds are becoming more competitive in relation to other types of ART.



**Figure 6:** Multiple of Spread over Expected Loss Evolution

This figure represents the evolution multiple of spread over expected loss development in basis points. A trend line was additionally added to better interpret the results. The data is relevant to the period from December 1996 to March 2015.

### 3.1. Descriptive Statistics

In this Section we present several descriptive statistics relevant to our sample, from December 1996 to March 2015. Table 2 details the number of cat bonds issued to date. In Panel A the cat bonds are sorted by country according to peril and trigger type. Across territories the most issue territory is the U.S. with more than half of the issues, whereas Europe accounts for only 6% of the total issues. In regards to covered peril in the United States (U.S.) the most issued cat bond peril type is multi-peril (143), followed by wind (105) and earthquake (55). In Europe cat bonds cover mainly wind, whereas for Others (Japan, Mexico and multi-territory) the most of the issues are multi-peril bonds. Moreover, when analyzing the trigger type in U.S. the most common trigger is indemnity, whereas for Europe and Others the parametric index is the most used. Overall, the most common peril is multi-peril (58%) and the trigger type is indemnity (32%), followed by industry loss (25%) and parametric index (22%).

Table 2 Panel B shows the most common groupings of peril and territories detailed according to the trigger type. U.S. x Wind is the most common type of grouping. Europe x Wind cat bonds account for 75% of the total number of issues in Europe. One can infer that U.S. x Wind cat bonds are mainly indemnity triggered, this conclusion is in line with Panel A. While, U.S. X Earthquake are industry loss trigger (33%), closely followed by parametric (25%) and indemnity (22%). Europe x Wind and Japan x Earthquake cat bonds are mainly parametric triggered, the same we infer in Panel A.

<b>Panel A</b>						
	U.S.	Europe	Others	Total		
<b>Peril</b>						
Wind	105	29	27	161		
Earthquake	55	2	30	87		
Multi	143	5	188	336		
<b>Total</b>	<b>303</b>	<b>36</b>	<b>245</b>	<b>584</b>		
<b>Trigger</b>						
Indemnity	131	4	51	186		
Industry Loss	107	8	32	147		
Parametric	20	20	86	126		
Modeled Loss	20	2	16	38		
Multi	24	0	57	81		
<b>Total</b>	<b>302</b>	<b>34</b>	<b>242</b>	<b>578</b>		
<b>Panel B</b>						
	Indemnity	Industry Loss	Parametric	Modeled Loss	Multi	Total
U.S. x Wind	53	38	5	2	7	105
U.S. x Earthquake	12	18	14	4	7	55
Europe x Wind	2	7	18	0	0	27
Japan x Earthquake	7	0	11	1	1	20
<b>Total</b>	<b>74</b>	<b>63</b>	<b>48</b>	<b>7</b>	<b>15</b>	<b>207</b>

**Table 2:** Number of Cat Bonds per Category

This table shows the number of cat bonds issued from December 1996 to March 2015. Panel A shows the data by peril and trigger type for each relevant region, United States of America (U.S.), Europe and others (Japan, multi-territory, Mexico, etc). Panel B describes the number of cat bonds issued in the same period by groupings of peril / territory and trigger type.

The descriptive statistic values for the main bond characteristics of 589 cat bond tranches are shown in Table 3. The spread has a mean of 818 bp and 220 bp for the expected loss. The spread varies significantly across cat bond tranches, as specified by the great standard deviation (Stdev.). Expected loss in contrast has low standard deviation and varies from 1 to 1423 bp. The multiple, cat bond spread times expected loss, is on average 9.6, with a median of 4.2. These values are greater than Dieckmann (2009) who finds an average multiple of 4.3 and media 3.8 for a smaller sample of 61 cat bond tranches. Moreover, the average issue size is of 112 million USD, with the largest issue of 1.5 billion USD. Furthermore, the average cat bond maturity is 41 months (3.4 years), while the minimum is 1 month and the longest maturity of 81 years.

The descriptive statistics in Table 3 when eliminating the outliers, winsorized mean, suffer small changes. For instance the minimum spread doubles and the maximum decreases by around 1000 bp and the S.D. decreases by 15 bp. Cat bond issue size reduces to 950 US dollar millions. Term S.D also decreases by one year due to the decrease in the maximum maturity

decreasing in around 2 years. The remaining cat bond characteristics do not suffer significant variations.

Variable	Mean	Median	Stdev.	Max.	Min.
Spread (bp)	818.29	675.00	571.12	4920.00	65.00
Expected Loss (bp)	220.02	149.00	216.23	1423.00	1.00
Risk Premium (bp)	845.23	800.00	423.45	2200.00	250.00
Multiple	9.57	4.23	39.66	603.00	0.01
Size (USD mn)	111.60	80.00	119.93	1500.00	1.60
Term (months)	40.94	36.03	70.77	972.69	1.02

**Table 3:** Descriptive Statistics for the Sample of 584 Cat Bonds

This table shows the mean, median, standard variance (S.D.), maximum (max.) and minimum (min.) for the full cross section of 589 cat bonds relative to the spread, expected loss, risk premium in basis points (bp), as well as size in million USD (USD mn) and term in months. The cat bond sample is from December 1996 to March 2015.

Table 4 displays the descriptive statistics for the different categories of cat bonds. While analyzing the data on geographical territory, it is observable that U.S. leads in issues with 52%, the second largest territory issue is multi-territory with 33%, and as a consequence of its predominance in the market those have the highest average spreads. However, when comparing issues in size and term, we can see that U.S and multi-territory present lower values than for Japan, Europe and Other. When comparing cat bond characteristics across perils we can see that more than half of the issues are multi-peril (57%), whereas wind and earthquake account for 28% and 15% respectively. Earthquake cat bonds present lower spread, expected loss, risk premium and multiple, contrary to wind and multi-peril issues which can be interpreted as the later carrying more risk as well as higher compensation. Multi-peril issues seem to be the most attractive of the three since those provide a higher multiple (spread to expected loss). Furthermore, the most issued trigger types of bonds are indemnity triggers (32%), industry loss (25%) and parametric index (22%). The higher spread exhibit is for multi-trigger and the lowest for indemnity. The later bond type is supposed to compensate investors for bearing the issuer moral hazard, which is rewarded by the high multiple. Cat bonds issued pre Hurricane season and at the year-end pay higher spreads and have shorter maturities. Additionally, Swiss Re issued bonds account for almost one third of the total issues (27%) the higher spread, expected loss, risk premium and multiple and in contrast the lower issue size and term. A possible reason for the size to be half when comparing to the all sample is that this sponsor is issuing more through shelf offerings, which have lower issue sizes. These results are in line with the fact that Swiss Re is the market leader in the cat bond market and is innovator. BBB rated bonds account for 8% of the all

sample of cat bonds, these bonds carry a lower spread, expected loss and risk premium. Although, the multiple is the highest, derived from low expected loss values, resulting in a particularly high compensation for investors.

	#	%	Spread (bp)	EL (bp)	RP (bp)	Multiple	Size (USD mn)	Term (months)
<b>Territory</b>								
U.S.	304	51.88%	813.94	188.83	899.85	10.88	125.54	36.09
Europe	37	6.31%	615.54	207.84	562.22	2.75	132.13	39.11
Japan	29	4.95%	337.28	82.39	431.25	9.11	135.34	53.26
Other	24	4.10%	663.42	280.56	643.75	2.45	97.97	50.20
Multi	192	32.76%	975.13	287.37	913.89	9.84	84.36	46.79
	586	100%						
<b>Peril</b>								
Wind	162	27.69%	769.80	201.68	791.22	9.76	128.83	40.10
Earthquake	87	14.87%	463.75	122.13	481.00	6.92	137.61	36.89
Multi	336	57.44%	929.24	249.03	955.64	10.12	95.43	41.57
	585	100%						
<b>Trigger</b>								
Indemnity	186	32.12%	696.09	154.18	852.24	17.43	139.26	49.39
Industry Loss	147	25.39%	813.99	204.92	880.00	5.28	127.16	37.15
Parametric Index	127	21.93%	685.93	231.74	600.00	4.92	77.73	39.40
Modeled Loss	38	6.56%	741.40	148.65	773.00	7.10	100.35	37.51
Multi	81	13.99%	1231.36	384.41	901.92	4.28	75.07	27.86
	579	100%						
<b>Seasonality</b>								
Hurricane	204	34.63%	812.75	189.85	756.73	10.76	103.49	33.44
Year -end	110	18.68%	953.57	299.04	1040.28	4.22	100.56	31.61
Other	275	46.69%	767.68	211.18	826.89	10.94	122.03	50.81
	589	100%						
<b>Sponsor</b>								
Swiss Re	159	26.99%	1182.06	371.18	936.84	9.62	58.49	25.82
Other	430	73.01%	716.55	175.81	777.78	9.32	125.27	42.60
	589	100%						
<b>Rating</b>								
High Yield	542	92.02%	550.39	341.39	224.95	9.32	82.69	19.03
BBB Rating	47	7.98%	356.74	459.68	15.49	10.92	45.35	16.26
	589	100%						

**Table 4:** Different Categories of Cat Bonds Descriptive Statistics

This table shows the number (#) and percentage (%) of cat bond tranches from December 1996 to March 2015, and its average spread, expected loss (EL), risk premium, multiple, size and term according to territory covered, peril, type of trigger, seasonality, sponsor and rating class.

## 4. Pricing Determinants for Cat Bond Spread

Previous literature findings assume expected loss as the main driver for cat bond spread (Lane and Mahul, 2008; Dieckmann, 2009; Galeotti et al., 2013). In this work our focus is on determining further cat bond spread determinants at issuance. In Section 3 after analyzing the descriptive statistics of the cat bonds characteristics we find that besides expected loss there are other factors influencing cat bond spread. However, expected loss is still the major influencer of spread. Hence, in order to determine which are the main characteristics of cat bonds influencing the spread we run a series of OLS regressions for the cat bond spread ( $S^{Cat}$ ):

$$(1) S^{Cat} = \alpha + \beta_i x + \varepsilon_i$$

where  $x$  is a vector  $x$  (2) of:

$$(2) x = [EL; Size; Term; Indem; Wind; Earthquake; Multi; U.S.; Europe; Japan; U.S. x Wind; U.S. x Earthquake; Europe x Wind; Hurricane; YearEnd; ROL; Sponsor; BBBRating; BBSpread]$$

The spread ( $S^{Cat}$ ) is measured in bp, whereas expected loss (EL) in percentage points (pp), size describes the issue volume in million US dollars and term is represented in months. Indemnity is a dummy variable controlling trigger type that equals one if the transaction is built as indemnity trigger and zero else. Additionally, dummy variables to control peril type are added, wind, earthquake equal one if cat bonds belong to this catastrophic event and when both dummy variables equal zero then represents a multi-peril transaction. Moreover, territory dummies are created for United States (U.S.), Europe, Japan and multi-territory (Multi). Interaction between perils and territory are also considered for peak perils and peak territories. In order to control for the seasonality of cat bond issuance, in the second quarter (May and June) pre to the Hurricane season (Hurricane) and the closing of the year (YearEnd) dummy variables are added to the model. In addition, Swiss Re binary variable is added to control the sponsor. Analogous investment grade (BBBRating) dummy is created and assumes the value of one when the rating is from BBB- upwards. RoL and BB corporate bond spread (BBSpread), are measured in pp and control for the cyclical spread, are added to the model. These regressions are computed with data from December 1996 to March 2015.

While constructing our vector  $x$  we define our main hypothesis, based on the bond specific characteristics such as term, size and trigger type (Dieckmann, 2009). Firstly, we aim to

question if the cat bond spread decreases with size and term and also if higher spread is linked to indemnity cat bonds. Secondly, hypotheses are based on the reference peril and cover territory. We then question whether spread tends to be larger in peak territories or peak perils than in non-peak territories and non-peak perils. Thirdly, the relation between peak territories and perils results in higher spreads is examined. Also, hot issue seasons tend to have higher spreads is tested for Hurricane Season and the year end. In addition, we test if higher spreads are paid by well-known sponsors. And if bonds associated with higher rating bonds pay lower spreads. Moreover, if spread presents a similar behavior with reinsurance cycle or whether BB spreads have a positive effect on cat bond spread are tested.

In Table 5 the regression of the vector  $x$  (2) (Model 1) is exhibited, out of the initial sample of 589 cat bond tranches, only 396 are regressed due to the lack of sufficient data available. Our findings are in line with previous literature findings, in which expected loss is significant for the model. This result is not surprising since expected loss is the measure of the cat bond inherent risk (Dieckmann, 2009). Issue size in a bond measures the availability of a bond in U.S. dollar amount; an equivalent line of argument can be drawn for the term in number of months. Our hypothesis related to liquidity, size is confirmed. Larger cat bond issues reflect into a lower spread, which is expected since investors require additional reward for a potentially illiquid market (Dieckmann, 2009). Contrary to Braun (2014) findings, the term hypothesis is also confirmed and thus the cat bond spread tends to decrease in regards to term. It is probable that a trigger associated with reporting losses leads to a moral hazard question perhaps replicating in higher spreads (Dieckmann, 2009). The hypothesis of test that indemnity cat bonds are priced above expected loss is rejected. Moreover, wind and earthquake perils present low spreads and confirm the hypothesis that spreads are larger for peak perils. In regards to territory hypothesis, peak territory is considered to be U.S. and multi-territory where the hypothesis that spread tends to be larger in peak perils is confirmed. Relations between territory and perils are found for U.S. Wind, confirming a positive relation with spread. The seasonal effect influence on the cat bond spread is rejected for Hurricane Season. All the additional factors of cat bond spread hypotheses are confirmed, results which are in line with Braun (2014). The sponsor (Swiss Re) and BB spread have a positive impact on spread. The spread is found to behave similar to the reinsurance cycle, whereas high rating bonds (BBB Rating) are associated with lower spreads. Overall, our findings are that there exist other drivers of cat bond spread besides expected loss. However, the  $R^2$  of 66% indicates that the model still presents a low fit.

Lastly, the Breusch-Pagan (BP) test is performed in order to test if the variance errors are constant, homoskedasticity. We reject that homoskedasticity exists and confirm heteroskedacity. Also the White Test (WT) is performed, a more generic test than BP. In Model 1 heteroskedacity is verified, which classifies non-constant volatility for periods when high or low future volatility cannot be seen.

<b>Model 1</b>		
	coeff.	p-val.
Intercept	-477.67***	0.00
Expected Loss	188.10***	0.00
Size	-0.32***	0.04
Term	-0.43**	0.09
Indemnity	-3.79	0.93
Wind	-380.91***	0.00
Earthquake	-257.16***	0.01
Multi	396.05***	0.00
U.S.	345.98***	0.00
Europe	529.57***	0.01
Japan	391.24***	0.00
U.S. x Wind	436.76***	0.00
U.S. x Earthquake	95.18	0.47
Europe x Wind	-111.06	0.59
Hurricane	21.65	0.62
Year End	-96.80**	0.06
Sponsor	105.41**	0.05
RoL	440.28***	0.00
BBBRating	-161.63**	0.08
BBSpread	23.92**	0.07
df	393	
SEE	84.94	
Adj. R <sup>2</sup>	0.66	
WT	226.64***	0.00
BP	302.33***	0.00

**Table 5: Model 1 - Cat Bond Spread Determinants**

This table shows for the sample of 589 cat bond tranches, from December 1996 to March 2015, least squares estimates of unstandardized coefficients (coeff.) and p-values (p-val.). The significance level tests are also presented where \* represents 15%, \*\* denotes 10% and \*\*\* 5%. In addition, the degrees of freedom (df) for the subsamples models are shown. The adjusted R<sup>2</sup> and the standard error of the estimates (SEE) measure the variance and the goodness of fit of each model. White's test (WT) and Breusch-Pagan (BP) test have been computed to address heteroskedasticity, which classifies non-constant volatility for periods when high or low future volatility cannot be seen.

After the first regression analysis to the Model 1 the variables term, earthquake, Europe, Japan and U.S. x Wind even though statistically significant are removed from the model, due to the fact that in the previous Section (Descriptive Statistics) those were the less influential.

Indemnity is kept in the vector since in the earlier Section we infer that it is the most issued form of trigger. This intermediary vector  $x$  is not presented since it was considered to be a transitory step. Further analysis is conducted and the not statistically significant variables indemnity, wind and size are then removed from the vector. Consequently, these changes result in vector  $x$  (3):

$$(3) x = [EL; Multi; U.S.; RoL; Sponsor; BBBRating; BBSpread]$$

The results from the regression vector  $x$  (3) (Model 3) are presented in Table 6, where all the cat bond characteristics coefficients are significant and thus confirming our previous hypotheses in test. The cat bond spread is strongly influenced by expected loss, the higher the expected loss the greater the spread. Moreover, the peak territories: U.S. and Multi have also a positive impact on the spread. Swiss Re as the issue sponsor tends to increase the spread. The cat bond spread behaves similarly to the reinsurance cycle (RoL). The bonds rating have a negative impact on the spread and the corporate bond spread is the least influential characteristic in analysis. Model 3 results in a  $R^2$  of 62% and we reject both tests for homoskedasticity.

<b>Model 3</b>		
	coeff.	p-val.
Intercept	-343.94***	0.01
Expected Loss	188.92***	0.00
Multi	282.24***	0.00
U.S.	293.27***	0.00
Sponsor	100.47***	0.04
RoL	324.31***	0.00
BBBRating	-168.38**	0.06
BB Spread	22.216**	0.09
df	395	
SEE	63.48	
Adj. $R^2$	0.62	
WT	63.95***	0.00
BP	288.69***	0.00

**Table 6: Model 3 - Cat Bond Spread Determinants**

This table shows for the sample of 589 cat bond tranches, from December 1996 to March 2015, least squares estimates of unstandardized coefficients (coeff.) and p-values (p-val.). The significance level tests are also presented where \* represents 15%, \*\* denotes 10% and \*\*\* 5%. In addition, the degrees of freedom (df) for the subsamples models are shown. The adjusted  $R^2$  and the standard error of the estimates (SEE) measure the variance and the goodness of fit of each model. White's test (WT) and Breusch-Pagan (BP) test have been computed to address heteroskedasticity, which classifies non-constant volatility for periods when high or low future volatility cannot be seen.

A correlation analysis is also performed, in order to assess the accuracy of the model variables relation, and no correlation is found which leads to our assumption that the model presents a good in sample fit.

After the regression of the Model (1) to (3) it is found the main drivers of the cat bond spread to be expected loss, peak territory (U.S. and multi-territory), sponsor, reinsurance cycle, investment grade and corporate bond spread. Additionally, an econometric model (4) is run across time and across perils for the same data sample, vector  $x$  (4):

$$(4) x = [EL; Peak; ROL; Sponsor; BBBRating; BBSpread]$$

Table 7 shows the results from  $x$  (4) (Model 4) in regards to peril are presented and are in line with our outlooks from the previous models, in which all variables are statistically significant. The time-series analysis results are inconclusive, as a result of the lack of data for some of the time periods. As an illustration, the sample is divided from June 1996 to December 2013 where only 25 bonds with all data is available, for the other three periods in analysis there were around 110 cat bonds. The resulting  $R^2$ 's are significantly lower than for perils, in addition most of the cat bond spread drivers are not significant.

In Table 7 the expected loss influence on spread increases in around 5 basis points to 188 bp. The peak territory spread decreases in a value comparing the previous values for U.S. and multi-territory. Also the variable sponsor witnesses a spread decrease in comparison to other issuing entities. Reinsurance cycle declines to 98bp, investment grade rating spread widens the spread and BB corporate bond remains almost the same. Across perils, the fit of the model maintains high. However, for the wind bonds the sponsor is no longer a major driver of the spread, and expected loss decreases its explanatory value. When controlling Earthquake cat bonds we conclude that neither Sponsor nor BB corporate bond spread drive the spread. Multi-peril bonds spread are found not to be influenced by the reinsurance cycle. In addition, WT is conducted and BP not since the later cannot be performed without the intercept variable. The results infer that for all models heteroskedasticity is confirmed. Hence, the econometric model presents a better fit to explain the cat bond spread at issuance, with a  $R^2$  of 87%.

	All Natural Perils		Wind		Earthquake		Multiperil	
	coeff.	p-val.	coeff.	p-val.	coeff.	p-val.	coeff.	p-val.
EL	187.63***	0.00	161.07***	0.00	146.64***	0.00	191.65***	0.00
Peak	242.96***	0.00	259.62***	0.01	109.82***	0.03	297.17***	0.00
Sponsor	91.78**	0.06	167.43	0.16	14.82	0.78	114.48***	0.04
RoL	97.97**	0.06	331.30***	0.00	173.09***	0.01	-11.39	0.88
BBBRating	-194.5***	0.03					-183.49***	0.04
BBSpread	21.95**	0.10	-52.99*	0.11	-3.22	0.87	48.00***	0.00
df	396		122		51		222	
SEE	43.23		76.15		39.12		52.04	
Adj. R <sup>2</sup>	0.87		0.79		0.93		0.92	
WT	53.81***	0.00	45.87***	0.00	37.64***	0.00	070***	0.00

**Table 7:** Peril Cat Bonds Subsample Econometric Model Robustness Check

This table shows for the sample of cat bond tranches from December 1996 to March 2015. The least squares estimates of unstandardized coefficients (coeff.) and p-values (p-val.). Also, the significance level where \* represents 15%, \*\* denotes 10% and \*\*\* 5%. In addition, the degrees of freedom (df) for the subsamples models are shown. Also the adjusted R<sup>2</sup> (Adj.R<sup>2</sup>) and the standard error of the estimates (SEE) measures explain variance and the goodness of fit of each model. White's (WT) was computed to address heteroskedasticity, which classifies non-constant volatility for periods when high or low future volatility cannot be seen. EL stands for expected loss, Peak for peak territories (U.S. and Multi-territory), Sponsor is Swiss Re, RoL is the Rate OnLine Index, BBBRating represents the Investment grade (bonds rated above BB+), BBSpread is the U.S. High Yield BB Option-Adjusted Spread.

## 5. Robustness Check with Actuarial Alternatives

In this Section, we study further alternatives to analyze the spread drivers, and to foresee the extent to which the econometric vector model has a good in sample fit. Thus, by means of OLS we test five common actuarial alternative models, used in previous studies.

The first model we run is a linear model of the spread ( $S^{Cat}$ ) to the expected loss (EL):

$$(5) S^{Cat} = \alpha + \beta EL_i$$

Table 8 shows the results that infer the higher the expected loss the higher the spread. This model results in a R<sup>2</sup> of 57%, value lower than the econometric vector model in the previous section. Secondly, we regress the spread using a polynomial model in natural logarithm (log) of EL:

$$(6) S^{Cat} = \alpha + \beta Ln(EL_i) + \gamma Ln(EL_i)^2$$

The outcomes from the model confirm that all variables of the model are significant to explain the cat bond spread at issuance. The natural log of the EL has a greater impact on the

spread than the squared natural log of EL. This model  $R^2$  is lower than the previous, 54%. Thirdly, the Lane (2000) model on the probability of first loss (PFL) and conditional expected loss (CEL) is computed:

$$(7) S^{Cat} = EL_i + \alpha PFL_i^\beta CEL_i^\gamma$$

This model has the lowest  $R^2$  of 36% among all the models in study. In Table 8 we see that the CEL is not statistically significant. Additionally, a power function model of the spread to EL by Major and Kreps (2002) is analyzed:

$$(8) S^{Cat} = \alpha EL_i^\beta$$

The findings from Major and Kreps (2002) are that the coefficients are significant and low  $R^2$  of 47%. Finally, ILS fund Fermat Capital model, where  $\lambda$  represents the Sharpe Ratio and  $\varepsilon$  the peril rank. The peril rank takes the values of 1 for U.S .x Wind and multi-peril, 2 for U.S .x EQ, 3 for Europe x Wind and 4 for Japan x EQ, other transactions are ranked with 5 (Jaeger et al., 2010).

$$(9) S^{Cat} = EL_i + \lambda \sqrt{\frac{EL_i(1-EL_i)}{\varepsilon_i}}$$

This model gives the higher  $R^2$ , 83%, among the actuarial alternative models, however it is lower than the econometric vector model from the previous Section which seems to have a better in sample fit and explanatory power,  $R^2$  of 87%.

Moreover, WT results lead us to reject homoscedasticity and confirm heteroskedacity for all models. BP test is also performed and we reject homoscedasticity for all models expect for Major and Kreps (2002). A possible explanation for the contradictory results between both tests is that WT is more generic and can catch more general forms of heteroskedacity.

Hence, across all the alternative actuarial models the coefficients are statistically significant, when performing an in sample fit, inferring that expected loss is, once again, the major driver of cat bond spread at issuance.

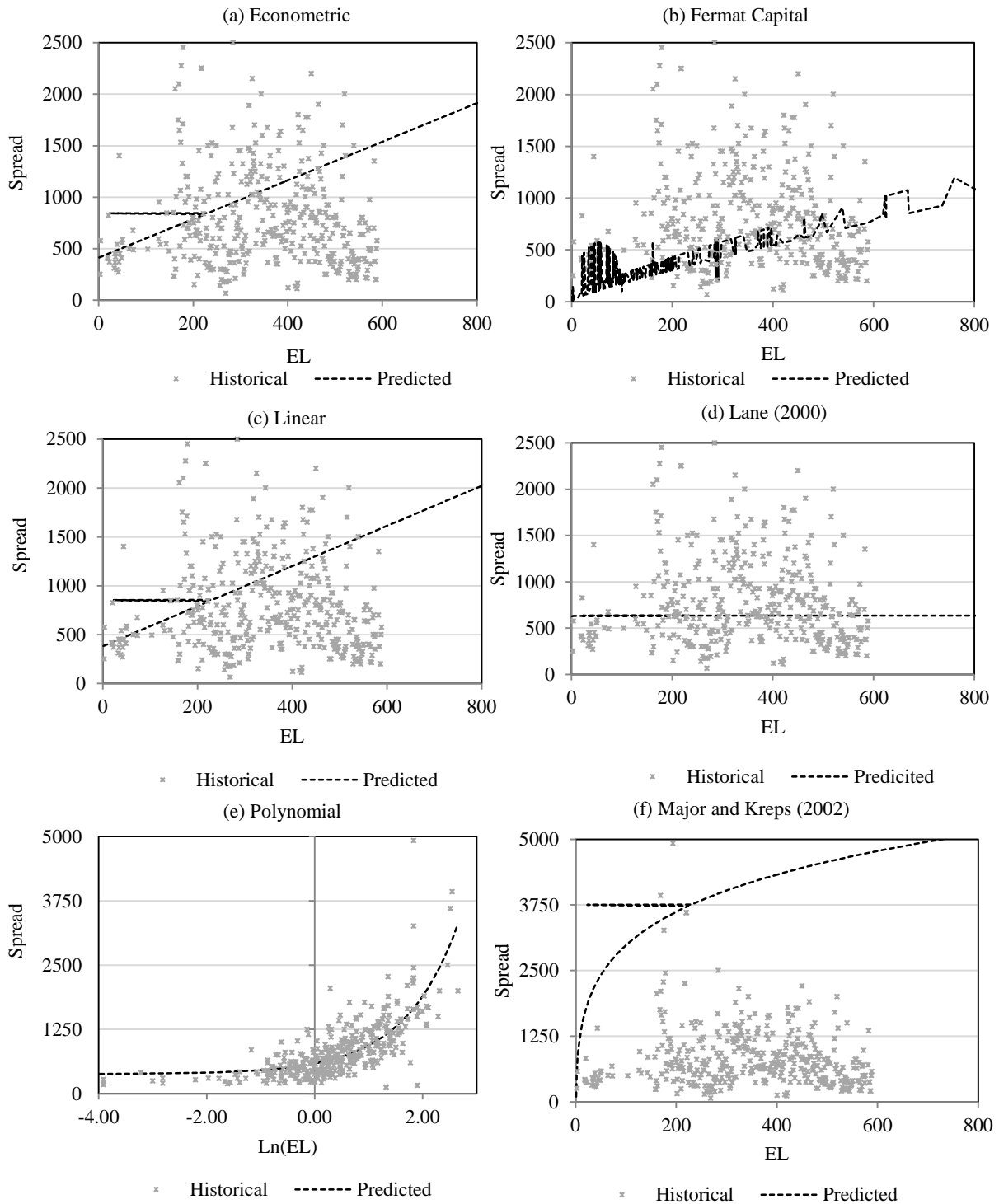
		Panel A				Panel B				
		$\hat{\alpha}$	$\hat{\beta}$	$\hat{\gamma}$	$\hat{\lambda}$	df	SEE	Adj.R <sup>2</sup>	WT	BP
Linear	coeff.	381.90***	205.15***			395	18.19	0.57	27.76***	238.80***
	p-val.	0.00	0.00						0.00	0.00
Polynomial	coeff.	573.56***	405.29***	88.64***		393	18.71	0.54	39.55***	241.38***
	p-val.	0.00	0.00	0.00					0.00	0.00
Lane (2000)	coeff.	1.61***	0.25***	0.03		339	0.06	0.36	18.05***	4.77***
	p-val.	0.00	0.00	0.78					0.00	0.03
Major Kreps (2002)	coeff.	1.85***	0.39***			393	0.02	0.47	18.57***	0.39
	p-val.	0.00	0.00						0.00	0.53
Fermat Capital	coeff.				16.37***	121	0.67	0.83	104.4***	
	p-val.				0.00				0.00	

**Table 8: Alternative Models In Sample Fit**

This table shows the results of the cat bond data from December 1996 to March 2015. In Panel A the least squares estimates of coefficients (coeff.), p-values and significance level where \* represents 15%, \*\* denotes 10% and \*\*\* 5%. Panel B shows the degrees of freedom (df) for the models proposed in previous literature, the Adjusted R<sup>2</sup> (Adj. R<sup>2</sup>) and the standard error of the estimates (SEE) measures explain variance and the goodness of fit of each model. White's test (WT) and Breusch-Pagan (BP) test have been computed to address heteroskedasticity, which classifies non-constant volatility for periods when high or low future volatility cannot be seen.

With the aim of better understanding the results from the previous in sample fit of the alternative actuarial models, we look to Figure 8 where the graphic representation of each model is plotted. The dashed lines represent the predicted and the dots the historical values of spread and expected loss (EL). In the multifactor models, econometric and Lane (2000) all other variables besides expected loss and spread are set to their sample mean.

The results are in line with the previous findings, in which the econometric model (a) developed in this work is the one providing a better in sample fit, followed by Fermat Capital (b), the linear (c) and the polynomial (e). Lane (2000) (d) and Major and Kreps (2002) (f) show the same conclusion as the in sample fit analysis.



**Figure 7: Alternative Models in Sample Fit Graphic Representation**

These plots represent the in sample fit of the five alternative models estimated by means of OLS for a cat bond sample from December 1996 to March 2015. The dashed line represents the predicted values of the spread for each model for different scales of expected loss, in basis points. In the multifactor models such as Lane (2000) and econometric all other variables besides expected loss are set to their sample mean. In Fermat Capital Model the peril rank has been set to 2.5.

## 6. Robustness Check with Out-of-Sample Analysis

Following the in sample fit, an out-of-sample performance is developed, for the reason that an in sample fit is not translated into an out-of-sample accurate performance. Typical out-of-sample measures were calculated (Xu and Taylor, 1995), in order to evaluate the forecasting performance by examining the forecasted error.

Table 9 presents the results of the forecasting error models for three calibration samples. In Panel A the calibration sample is set from December 1996 to December 2008 to estimate the coefficients from January 2009 to March 2015. In this panel 168 cat bonds data is used to estimate the remaining 230. Panel B and C have a larger calibration sample, December 2008 to December 2010 and December 1996 to December 2012 respectively. The estimated values are less than in Panel A, 164 and 131 correspondingly.

Firstly, we calculate the mean forecast error (ME), where  $N'$  illustrates the number of transaction in the sample,  $S_i^{Cat}$  represents the spread of each transaction,  $\hat{S}_i^{Cat}$  is the spread from the pricing model:

$$(10) \quad ME = \frac{1}{N'} \sum_{i=1}^{N'} (S_i^{Cat} - \hat{S}_i^{Cat})$$

Lane (2000) presents the lowest error across the three estimation periods, whereas the econometric model the highest forecast errors. Secondly, the mean absolute error (MAE) is computed:

$$(11) \quad MAE = \frac{1}{N'} \sum_{i=1}^{N'} |S_i^{Cat} - \hat{S}_i^{Cat}|$$

We find that Lane (2000) and Major and Kreps (2002) have the lowest forecast error. The econometric model and ILS Fermat Capital model have the greater errors. Although, in the in sample fit presented the better in sample fit across all models. Subsequent the root square error (RMSE) is estimated:

$$(12) \quad RMSE = \sqrt{\frac{1}{N'} \sum_{i=1}^{N'} (S_i^{Cat} - \hat{S}_i^{Cat})^2}$$

The results infer that the lowest forecast error to be of the Lane (2000), Major and Kreps (2002), linear and polynomial models. Furthermore, we introduce an out-of-sample  $R^2$  ( $R^2_{OS}$ ),

since this statistic and the  $R^2$  statistic can be compared (Campbell and Thompson, 2008). In this statistic  $\hat{S}_i^{Cat}$  denotes the historical average spread in the fitted sample:

$$(13) \quad R^2_{OS} = 1 - \frac{\sum_{i=1}^{N'} (S_i^{Cat} - \hat{S}_i^{Cat})^2}{\sum_{i=1}^{N'} (S_i^{Cat} - \hat{S}_i^{Cat})^2}$$

The findings show that across all calibration samples the Linear model presents the highest  $R^2_{OS}$  of 98%, 96% and 96%. Followed, by Fermat Capital model with  $R^2_{OS}$  of 91%, 92% and 92%. The later model also presents a good in sample fit.

Hence by analyzing the results, one can infer that across all three calibration samples Lane (2000) has the lowest forecasting error values, followed by Major and Kreps (2002) and linear model in expected loss. The econometric model which in the in sample fit presented the best fit; in the out-of-sample performance we find the largest forecasting errors across all the statistics in analysis.

	Panel A				Panel B				Panel C			
	ME	MAE	RMSE	$R^2_{OS}$	ME	MAE	RMSE	$R^2_{OS}$	ME	MAE	RMSE	$R^2_{OS}$
Econom.	454.62	485.58	569.02	-0.26	434.90	461.44	553.30	-0.73	433.21	457.45	520.75	-0.88
Linear	106.91	267.47	371.86	1.14	151.73	271.90	380.34	1.21	148.15	253.49	334.62	1.20
Polyn	133.31	271.82	359.11	-2.49	171.37	274.17	372.58	15.31	153.70	252.21	312.50	4.13
Lane	-15.43	271.81	352.65	0.76	43.34	259.32	336.33	1.61	58.95	278.06	360.03	1.64
M&K	24.27	230.59	314.46	1.34	76.54	242.50	323.46	1.72	68.09	225.55	280.82	1.51
FC	-378.65	378.65	478.87	0.70	-351.81	351.81	446.06	0.72	-348.78	348.78	456.71	0.72

**Table 9:** Out-of-Sample Alternative Models Performance

This table shows the out-of- sample performance measures suggested by previous literature for the five alternative models, econometric model (Econom.), Linear in expected loss (Linear), Polynomial in expected loss (Polyn), Lane (2000), Major and Kreps (2002) (M&K) and Fermat Capital (FC). Panel A represents the calibration sample from December 1996 to December 2008, with subsample of bonds issued (N) 168 and estimation (N') of 230. Whereas, the Panel B represents the calibration sample December 1996 to December 2010, where N 234 and N' 164. Panel C represents December 1996 to December 2012, with N 267 and N'131. The measures are the mean error (ME), mean absolute error (MAE), root mean squared error (RMSE) and out-of-sample R-squared ( $R^2_{OS}$ ).

## 7. Conclusion

The expectation that expected loss is the main driver of the cat bond spread is confirmed with our study. In addition, we prove that besides expected loss, some other cat bond specific characteristics influence the cat bond spread at issuance. These results are in line with Braun (2014) and other previous literature findings. Expected loss, peak territory (U.S. and multi-territory), reinsurance cycle, sponsor and BB spread are found to be the major spread drivers, whereas territory, peril, seasonality, issuance size, maturity and trigger type are not significant. The econometric pricing model, exhibits the best in sample fit with an adjusted  $R^2$  of 87%.

The market for cat bonds is of high potential due to catastrophic risks. Reinsurers and insurers are required to have large liquid reserves to be able to meet its claims if an event occurs. This is one of the main problems faced by insurers having sufficient retained earnings to reimburse in the event of natural disaster losses, since these events result in huge losses (Jafee and Russel, 1997). Thus, insurance securities can provide to insurers and reinsurers diverse opportunities to diversify and hedge the risk to financial markets (Cummins and Trainar, 2009).

Further research on the cat bond investors would be interesting in order to understand the influence of the cat bond on the holders' portfolio and find who the main players in the field are. It would also be interesting to study the demand of the cat bond at issue, versus its number tranches and final issue value. Moreover, an analysis regarding the secondary market could be done, in order to comprehend the spread deterrents after the bond being issued and traded.

## Appendix

Index Name	Font	Reference
Synthetic Rate on Line Index (RoL)	Thomson Reuters	Line(Q.LFSRLI)
Lane Financial Long Term Index of Catastrophe Reinsurance	Lane and Mahul (2008)	Appendix
Bank of America Merrill Lynch U.S. High Yield BB Option-Adjusted Spread	Thomson Reuters	Line(Q.JPMHSDBB)
Bank of America Merrill Lynch U.S. High Yield BB Option-Adjusted Spread	Federal Reserve Economic Data	<a href="http://research.stlouisfed.org/fred2">http://research.stlouisfed.org/fred2</a>

**Table 10:** Data Sources of Indices

This table shows the indices used in this study and its data sources (font), as well as the relevant acronym/ticker (reference) for each one.

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