Asset Pricing and Extreme Event Risk: Common Factors in Catastrophe Bond Funds

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Abstract

Catastrophe (cat) bond funds are an alternative and innovative investment opportunity. Although they are sometimes still classified as bond mutual funds or hedge funds, their returns behave unlike those of any other asset class. Thus, traditional asset pricing models, such as the five-factor approach of Fama and French (1993) and the seven-factor approach of Fung and Hsieh (2004), are not suitable for dedicated cat bond funds. The aim of this paper is to provide a detailed empirical analysis of these investment vehicles and to derive a factor model, which is able to explain both their time-series and cross-sectional return characteristics. Using a comprehensive dataset, we show that cat bond funds have historically exhibited a superior risk-adjusted performance. We then identify key return drivers and introduce a peril-based three-factor approach. Despite a strong overall fit, we are left with significant positive alphas for one quarter of all cat bond funds, which are either attributable to manager skill or to exotic beta exposures from other ILS market segments.

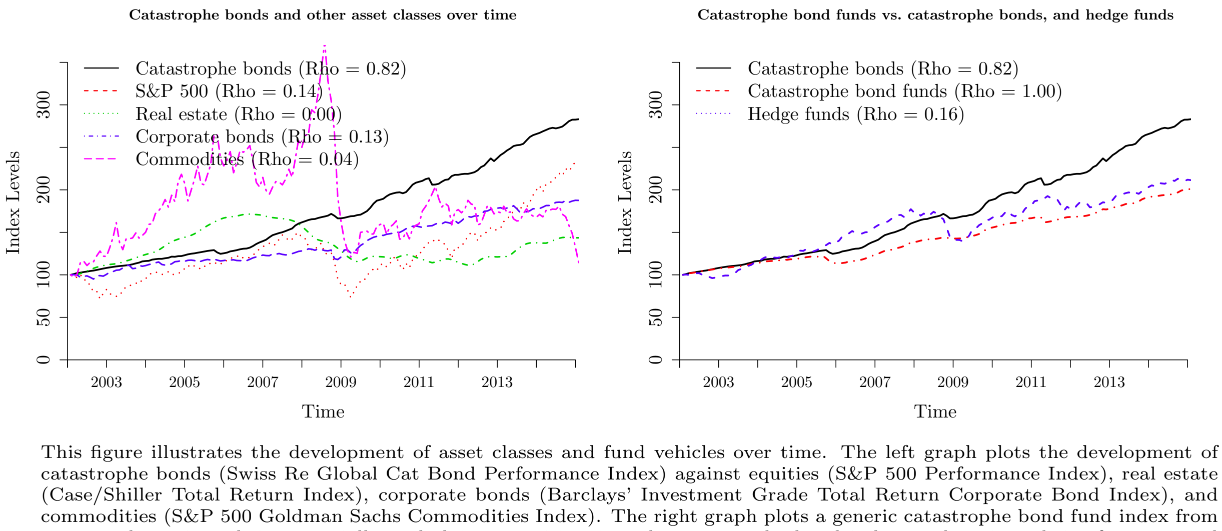
Key words: Catastrophe bond funds · Hedge funds · Factor Models · Performance · Cross-Section
JEL Classification: G13 · G22

1 Introduction

Over the last two decades, a new asset class called insurance-linked securities (ILS) has emerged. To date, the most popular instrument in this segment of the capital markets is the catastrophe (cat) bond, a security which pays regular coupons to the investor unless a disaster occurs during the contract term, leading to full or partial loss of principal. Cat bonds have been developed by (re)insurance companies as a hedge against extreme-event exposure in their property risk portfolios. They typically cover natural perils such as windstorms and earthquakes in different regions around the world and may be triggered either through insurance losses or physical parameter measurements in excess of a threshold.[1]

Throughout the last decade, the market for cat bonds has witnessed substantial growth rates. Its popularity among investors is based on the argument that cat bonds provide attractive and hardly-correlated returns with the broader markets (see Figure 1). However, directly investing in ILS and particularly cat bonds requires a lot of specific expertise (see, e.g., Braun et al., 2013). An alternative way to access this asset class is given by dedicated open-end cat bond funds. Although the latter are sometimes still classified as bond mutual funds or hedge funds, their returns exhibit a unique behavior.[2]

Figure 1: Asset classes and fund development



This figure illustrates the development of asset classes and fund vehicles over time. The left graph plots the development of catastrophe bonds (Swiss Re Global Cat Bond Performance Index) against equities (S&P 500 Performance Index), real estate (Case/Shiller Total Return Index), corporate bonds (Barclays' Investment Grade Total Return Corporate Bond Index), and commodities (S&P 500 Goldman Sachs Commodities Index). The right graph plots a generic catastrophe bond fund index from our sample against their potentially underlying securities, i.e., the catastrophe bond index, and against their often assigned fund category, i.e., hedge funds (HFRI Fund Weighted Total Return Composite Index). Behind each name the correlation ρ of the raw returns of each asset class with the raw returns of the cat bond fund index can be found. The time period is from January 2002 to December 2014.

[1] A detailed explanation of the structural features of cat bonds can be found in Braun (2016).

[2] A distinct characteristic of hedge funds is their ability to employ sophisticated strategies (e.g., short selling, leverage, and derivatives). Yet, the majority of hedge funds trades in traditional asset classes such as equities and fixed income. Cat bond funds, in contrast, focus on the entirely new market niche of investable insurance risk.

Despite the attractive risk-return profile and tremendous diversification potential offered by the asset class, little empirical research on the return drivers of cat bond funds has been conducted to date. The paper at hand aims at filling this gap. Our contribution is threefold. First, based on a comprehensive dataset, we analyze the performance of cat bond funds and identify distinctive features in relation to other asset classes. Second, to explain both the time-series and cross-sectional return characteristics of cat bond funds and enable style analysis as coined by Sharpe (1992) as well as Fung and Hsieh (1997), we derive several new asset pricing models. The latter include a parsimonious single-index model and a three-factor approach in the spirit of Fama and French (1992). Third, we draw on the factor models to examine whether certain cat bond funds are able to outperform their peers on a risk-adjusted basis.

Scholarly work on cat bond funds is rather scarce. The most relevant ideas for this paper relate to the hedge fund and bond fund literature. According to Fung and Hsieh (1997) there are three key determinants to evaluate the returns earned by a fund manager. These are the assets in the portfolio, the trading strategies, and the use of leverage. It is thus crucial to verify whether cat bond funds indeed offer a sufficiently large cat bond exposure. Fung and Hsieh (2004) also find that hedge funds exhibit significant tail risk due to short positions in put options on the market index. From a theoretical point of view, such a feature is inherent in cat bond funds as well. However, the realization of extreme meteorological or seismic events is very rare compared to the severe financial market crashes that hedge funds are exposed to. Another relevant strand of the literature deals with the pricing of the underlying cat bonds themselves (see, e.g., Galeotti et al., 2013; Braun, 2016; Gürtler et al., 2016). Extant studies in this field have focused on risk spreads instead of returns.

We show that cat bond funds exhibited a superior historical performance based on the Sharpe Ratio, the Sortino Ratio, the Excess Return on VaR, and the Calmar Ratio. Cat bond funds are also consistently delivering positive returns on an aggregate basis in approximately 90% of all analyzed months compared to a mere 67% during the same period for hedge funds. Furthermore, a three-factor model is able to explain the time series of cat bond fund returns with adjusted R-squares of around 70% which can be further increased to around 80% by including an option factor. Finally, despite the good fit of the three-factor model, we are left with significant positive alphas for one quarter of all cat bond funds in the cross section. These are either attributable to manager skill or to exotic beta exposures from other segments of the ILS market. Our findings shed light on the main return drivers of cat bond funds and should therefore be relevant to risk managers and investors alike.

The remainder of this manuscript is organized as follows. A description of our data both for the cat bond funds and the risk factors is provided in Section 2. In Section 3, we describe the factor models (classical and new) that form the center of our analysis. The empirical results are presented in Section 4, including the historical performance of cat bond funds, a series of time-series regressions, and an assessment of the models' ability to explain the cross-section of expected returns. In Section 5, we test the robustness of our results for various subperiods and alternative ILS indices. Section 6 concludes.

2 Data

2.1 Cat bond funds

We analyze a comprehensive cat bond fund dataset. In a first step, we identified all cat bond funds which are currently investable or were investable in the past to avoid any survivorship bias. For this purpose, we analyzed all funds reported by ILS-specific websites, such as `www.artemis.bm` or `www.insurancelinked.com`, various internet sources, press releases, and the Morningstar CISDM database. In a second step, we then retrieved monthly net-of-fee total return data for each fund from Bloomberg. From the same database we also collected information about the current assets under management (AuM), expense ratios, front and back loadings, performance fees, the share of the top ten holdings by the fund, and the share of cash holdings by the fund. If this information was unavailable on Bloomberg, we searched for it through various internet sources. As several funds do not report return data to Bloomberg, we also acquired return data under confidentiality agreements directly from the funds.[3] Furthermore, we did not include funds of funds in our sample. We controlled for any duplicate funds listed under a different name and used the institutional share class quoted in U.S. Dollars whenever available. We were able to identify a total of 55 funds with return data starting in January 2001 and ending in December 2014.

Table 1 shows the fund characteristics of the 55 cat bond funds. We report these characteristics first on an aggregate level under "All funds" and for each fund category as reported by Bloomberg (i.e., "Alternative", "Equity", "Fixed Income", "Mixed Allocation", or "Specialty"). As there is no catastrophe bond fund category, these funds are categorized based on the assessment of Bloomberg and

[3]It should be noted that Fermat Capital, which, with USD 4.7 bn of assets under management, is one of the four largest dedicated cat bond funds in existence, refrained from providing return information and is thus not included in our sample.

the self reporting by the funds. However, as stressed by Fung and Hsieh (1997), what the funds say they do is not necessarily what they actually do. Hence, the true investment style can only be assessed by means of factor models that explain the fund returns. Interestingly, the super-ordinate category by Bloomberg and the CISDM database for several catastrophe bond funds is hedge funds. The largest part of cat bond funds, however, falls within the super-ordinate category of "open-ended mutual fund". Thus, we decided to use Bloomberg's mutual fund categorization in the following.

Table 1: Fund characteristics

Classification	Time Period	# of Funds	Avg. AuM (USD millions)	Avg. Exp. Ratio (% p.a.)	Avg. Max. Load (Front and Back, % p.a.)	Avg. Performance Fee (% p.a.)	Avg. Fund Age (years)	Avg. Top 10 Holdings (% of AuM)	Avg. Cash holdings (% of AuM)
All funds	01/2001 - 12/2014	55	316.98	1.58	1.34	6.12	5.03	40.36	11.16
By Fund Category									
Alternative	07/2002 - 12/2014	19	297.74	1.59	0.53	8.05	4.48	39.63	7.26
Equity	09/2011 - 12/2014	3	286.69	0.96	0	8.33	2.11	67.7	1.44
Fixed Income	06/2001 - 12/2014	14	406.22	1.78	2.51	3.08	6.21	43.56	9.41
Mixed Allocation	08/2005 - 12/2014	7	219.47	1.76	1.75	7.5	3.62	26.17	29.32
Specialty	01/2012 - 12/2014	3	280.14	0.74	1.5	N/A	1.75	N/A	5.00
No Category	01/2001 - 12/2014	9	N/A	N/A	N/A	N/A	N/A	N/A	N/A
By Current Status									
Live Funds	01/2001 - 12/2014	43	377.27	1.56	0.98	6.34	5.49	40.97	10.24
Dead Funds	07/2002 - 10/2013	12	146.14	1.76	2.34	5.45	3.51	33.67	22.23

This table summarizes the fund characteristics of 55 catastrophe bond funds both aggregated ("All funds") and separated by category (i.e., the Bloomberg categories of "Alternative", "Equity", "Fixed Income", "Mixed Allocation", or "Specialty") and status (i.e., "Live" or "Dead"). Note that nine funds do not have a fund category or any fund information but do have return information which are used in following analyses. The table reports the classification, the time period, the number of funds in each classification, the average assets under management (AuM) in U.S. Dollar, the average expense ratio, the average maximum loading based on the sum of back and front loadings if charged, the average performance fee if charged, the average fund age in years, the average top ten holdings as a share of total AuM, and the average cash holdings as a share of total AuM. All fund figures are based on the last reported fund information. The sample starts in January 2001 and ends in December 2014.

In addition, we report fund characteristics for surviving funds and acquired or dissolved funds (i.e., "Live" or "Dead"). Based on the latest reported AuM of surviving funds, the total size of the catastrophe bond fund market is USD 16.22 billion. Based on the outstanding market volume of catastrophe bonds of USD 25.28 billion at the end of 2014 and under the assumption that catastrophe bond funds only invest in catastrophe bonds, this would imply that our sample covers approximately 64.41 % of the total market volume for catastrophe bonds. Swiss Re (2013) estimated that 61% of the outstanding cat bond volume is held by dedicated funds. Hence, our sample of funds should convey a quite complete picture of the market. We note that dead funds were slightly more expensive in terms of fixed costs such as the expense ratio or the front and back load in comparison to surviving funds. However, surviving funds charged a higher variable compensation (i.e., a higher performance fee of 6.34 % p.a. for surviving funds compared to 5.45 % p.a. for dead funds) suggesting that surviving funds tend to rely on a better performance to earn higher fees. On average a catastrophe fund is ca. 6 years old, illustrating the young age of this aspiring investment opportunity. Dead funds, however, discontinue their business after 3 $\frac{1}{2}$ years. Furthermore, surviving funds seem to focus on a larger amount of specific securities (i.e., 40.97 %) and hold a lower amount of cash in their funds in comparison to dead funds. This might indicate that funds who are able to survive have a certain expertise to differentiate between favorable and less favorable securities and, thus, focus on the more favorable securities whereas dead funds tried to diversify as much as possible.

2.2 Factors and indices

The catastrophe bond market factor is the Swiss Re Global Catastrophe Bond Index [Bloomberg ticker: SRGLTRR] which tracks the aggregate performance of all USD and EUR denominated catastrophe bonds capturing all ratings, perils, and triggers. For the *Perils Model* we use also include the Swiss Re U.S. Wind Catastrophe Bond Index [Bloomberg ticker: SRUSWTRR] tracking the total return for all single peril U.S. wind catastrophe bonds and the Aon Benfield Securities U.S. Earthquake Catastrophe Bond Index [Bloomberg ticker: AONCUSEQ] tracking the total return for all outstanding single peril U.S. earthquake catastrophe bonds. For the *Ratings Model* we use the Swiss Re (S&P)-BB-rated Catastrophe Bond Index [Bloomberg ticker: SRBBTRR] which tracks the total return for all outstanding USD denominated 'BB' catastrophe bonds, rated by S&P and Moody's at inception. As described above, we can further unfold the rating's component into three separate bond pricing elements. First, for TERM3Y we calculate the difference between Barclays 1-3 years U.S. Treasury Total Return Index [Datastream mnemonic: LHG13US] minus the 1-Month T-Bill rate. Second, DEFCOR is calculated as the difference between Barclays 1-3 years U.S. High Yield (Moody's BA) Total Return Index [Datastream mnemonic: LHHY13B] and Barclays 1-3 years U.S. Treasury Total Return Index. Third, DEFCAT is the difference between the Swiss Re BB-rated Catastrophe Bond Index [Bloomberg ticker: SRBBTRR] minus Barclays 1-3 years U.S. High Yield (Moody's BA) Total Return Index. Thus, we are able to match two total return bond indices with identical rating and maturity with each other, which should result in identical returns if the no arbitrage condition holds. Finally, we construct the factor CHIBINARY as the difference between the option return and the 1-Month T-Bill rate. CHIBINARY is the only synthetic factor in our framework as the instrument has ceased to exist. The option return is calculated as the potential payoff on the

CHI-Index.[4] Binary options on the CHI-Index were written at the Chicago Mercantile Exchanges but did not meet a sufficiently large demand in the last decade. Table 2 summarizes the statistical properties of the new factors and shows whether the factors are significantly different from zero.

Table 2: New factors

	Avg. Return (% per month)	Volatility (per month)	t-stat.	Median	Min.	Max.	Skewness	Kurtosis	Obs.
CATMKT	0.56	0.76	6.89***	0.52	-3.57	2.73	-1.39	10.08	156
SRBBCAT	0.46	0.91	4.78***	0.44	-4.90	2.99	-2.40	15.30	156
CATMKO1	0.19	0.21	8.54***	0.15	-0.65	0.94	0.23	5.33	156
TERM3Y	0.10	0.40	2.74***	0.09	-1.09	1.53	0.37	4.87	156
DEFCOR	0.32	1.89	1.69*	0.45	-11.31	7.59	-2.27	18.37	156
DEFCAT	0.04	1.77	0.23	0.10	-6.98	11.16	1.21	15.31	156
CATMKO2	0.12	0.49	2.73***	0.17	-3.52	1.14	-3.91	25.84	156
SRUSHU	0.65	0.95	6.57***	0.40	-2.17	4.45	0.83	5.98	156
AONUSEQ	0.41	0.58	7.58***	0.42	-5.83	1.46	-8.04	87.18	156
CHIBINARY	-0.72	8.09	-1.13	-1.32	-1.69	99.7	12.36	153.92	156

This table summarizes the new factors used for the catastrophe bond fund market. All factors are excess returns. The table reports monthly average return, volatility based on monthly returns, the median, the minimum, the maximum, the skewness, and the kurtosis of the excess return of the factors. The table also reports t-statistics of factors being significantly different from zero using Newey and West (1987) robust standard errors with lags of four. The last column reports the number of time-series observations. The factors start in January 2002 and end in December 2014. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

All factors are significantly different from zero except for DEFCAT and CHIBINARY. In the absence of arbitrage, it does not surprise that DEFCAT is zero although it peaks during different regimes in the corporate or the cat bond market. The fact that CHIBINARY is indifferent from zero results from the fact that it responds very rarely - to be specific it only heavily responded during Hurricane Katrina. Table 3 shows the correlation for the new factors and highlights the need to orthogonalize the catastrophe bond market factor (CATMKT) not only for interpretative reasons but also for statistical reasons due to the relatively high correlations between CATMKT, SRHUSU, and SRBBCAT.

[4]The Carvill hurricane index describes the theoretical damage from an Atlantic Hurricane and is proxied by hurricane parameters including the maximum sustained wind speed of the hurricane and the radius of the hurricane.

Table 3: Correlation

	CATMKT	SRBBCAT	CATMKO1	TERM3Y	DEFCOR	DEFCAT	CATMKO2	SRUSHU	AONUSEQ	CHIBINARY
CATMKT	1.00									
SRBBCAT	0.96	1.00								
CATMKO1	0.28	0.00	1.00							
TERM3Y	0.04	0.08	0.00	1.00						
DEFCOR	0.24	0.20	0.00	-0.44	1.00					
DEFCAT	0.23	0.28	0.00	0.28	-0.86	1.00				
CATMKO2	0.65	0.65	0.09	0.08	0.09	0.22	1.00			
SRUSHU	0.75	0.69	0.32	-0.01	0.20	0.14	0.00	1.00		
AONUSEQ	0.38	0.39	-0.01	-0.06	0.28	-0.09	0.00	0.34	1.00	
CHIBINARY	-0.05	-0.05	-0.01	0.05	-0.03	-0.01	-0.05	-0.03	-0.01	1.00

This table shows the correlation of the new factors for catastrophe bond funds. All factors are excess returns. The time period of the data is from January 2002 to December 2014.

Factors and asset classes that are used in other models to analyze their performance and usefulness include the Fama and French (1993) factors SMB, HML, and the Carhart (1997) momentum factor downloaded from Kenneth French's data library which is gratefully acknowledged (`http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html`). We also thank David Hsieh for making the hedge fund factors PTFSBD, PTFSFX, and PTFSCOM available on his website (`https://faculty.fuqua.duke.edu/~dah7/HFData.htm`). The excess market index MKTRF is the total return of the MSCI WORLD minus the risk free rate. *Convertible* is the total return of Merrill Lynch's All Convertible Index [Datastream mnemonic: MLCVXA0]. The usual TERM and DEF factors are calculated as the difference between the total return of the Barclays U.S. Long-Term Government Bond Index [Datastream mnemonic: LHGOVLG] and the risk-free rate and the difference between the total return of the Barclays U.S. Long-Term Corporate Bond Index [Datastream mnemonic: LHCCRLG] minus the Long-Term Government Bond Index, respectively. *Municipal* is the total return of the Barclay Municipal bond index [Datastream mnemonic: LHMUNIC] minus the risk-free rate. *Mortgage* is the total return of the Barclays U.S. Mortgage-Backed Securities Index [Datastream mnemonic: LHMNBCK] minus the risk-free rate. *Treasury* is the total return of the Barclays U.S. Treasuries Index [Datastream mnemonic: LHUSTRY] minus the risk-free rate. *HYield* is the total return of the Barclays Global High Yield Index [Datastream mnemonic: LHMGHYD] minus the risk-free rate. *Corporate* is the total return of the Barclays U.S. Corporate Bond Index [Datastream mnemonic: LHCCORP] minus the risk-free rate. *Real estate* is the total return of the Case/Shiller Composite-20 Home Price Index [Bloomberg ticker: SPCS20 Index] minus the risk-free rate. *Hedge fund* is the total return of the HFRI Fund Weighted Composite Index [Bloomberg ticker: HFRIFWI Index] minus the risk-free rate. *Commodity* is the return of the S&P

Goldman Sachs Commodities Index [Bloomberg ticker: SPGSCITR Index] minus the risk-free rate.

3 Factor models

To measure the performance and the asset allocation of cat bond funds we start with both traditional performance evaluation models in the spirit of Carhart (1997) and asset class factor models in the spirit of Sharpe (1992). We focus on bond and hedge fund factor models as catastrophe bond funds are often classified as either one of them. We then derive three innovative factor models to improve the performance measurement and asset allocation measurement of cat bond funds. All factors are measured as monthly returns in excess of the 1-Month T-Bill rate.[5]

3.1 Traditional factor models

The asset allocation model in the spirit of Sharpe (1992) includes different combinations (depending on correlations) of the equity market, a treasury bond index, a municipal bond index, a corporate bond index, a mortgage-backed securities index, a convertible bond index, a real estate index, a hedge fund index, and a commodities index.

The performance evaluation models include the Fama and French (1993) 5-factor model (i.e., including MKTRF, SMB, HML, TERM, and DEF) to account for the potential bond characteristics in cat bond funds, the Blake et al. (1993) 3-factor model, including the spread of a government bond index (TERM), a high yield bond index (*HYield*), and a mortgage-backed securities index (*Mortgage*), and the Carhart (1997) 4-factor model, which includes a equity momentum factor (MOM). Furthermore, we use the Fung and Hsieh (2004) 7-factor model including four of the five Fama and French (1993) factors described above plus three trend-following factors for bonds (PTFSBD), exchange rates (PTFSFX), and commodities (PTFSCOM). Note that in contrast to the original Fung and Hsieh (2004) 7-factor model we use excess returns instead of yields for the bond factors TERM and DEF, such that we can interpret alpha as an excess return as well (see Sadka, 2010).

[5]Although the definitions are blurred and quickly diffuse into each other, we define a performance measurement model as a model driven by risk factors meaning that these factors are *within* an asset class (e.g., high minus low exposure to a certain variable such as in the case of HML) whereas asset allocation factors capture an entire asset class. A distinction difficult to make is a factor model only incorporating a market factor which is a performance measurement model but also an asset allocation model.

3.2 New cat bond fund models

The first model, specifically addressing the returns of cat bond funds is a single-factor model in the spirit of the CAPM. We thus call this model the CAT-CAPM. The only factor in this model is an index of all catastrophe bonds denominated in USD and EUR, capturing all ratings, perils, and triggers. Assuming that cat bond funds only decide whether to invest in a diversified basket of cat bonds or not (i.e., hold cash instead) this model should be able explain all positive abnormal returns over time. Formally, the CAT-CAPM is defined as:

$$R_{p,t} - R_{f,t} = \alpha + \beta_{p,1} CATMKT_t + \epsilon_t, \tag{1}$$

with $CATMKT_t$ being the cat bond market factor in excess of the 1-Month T-Bill rate, $R_{p,t} - R_{f,t}$ being the return of the cat bond fund in excess of the 1-Month T-Bill rate.

However, as already mentioned, there are different types of cat bonds in the market which either securitize hurricane or earthquake risk. With meteorologists and geophysicists in the fund teams it could be a "manager skill" to strategically alternate between hurricane risk and earthquake risk to increase performance. We thus include a single-peril hurricane factor which tracks the performance of cat bonds with exclusive exposure to U.S. hurricanes as well as a single-peril earthquake factor which tracks the performance of cat bonds with exclusive exposure to U.S. earthquakes. Orthogonalizing the market factor on these two factors yields a new variable which tracks the performance of all remaining cat bonds with U.S. and non-U.S. multi-peril as well as non-U.S. single-peril exposure.[6] The orthogonalized market factor is thus useful for interpretative reasons. We will subsequently call this three-factor model the "Perils Model". It can be seen as an asset allocation model which tells us in which types of securities a cat fund invests (style analysis). Alternatively it can be interpreted as a risk model, since it identifies single-peril natural disaster risks inherent in the portfolio. Formally, the *Perils Model* is defined as:

$$R_{p,t} - R_{f,t} = \alpha + \beta_{p,1} CATMKO2_t + \beta_{p,2} SRUSHU_t + \beta_{p,3} AONUSEQ_t + \epsilon_t, \tag{2}$$

where $CATMKO2_t$ is the excess return of the market factor orthogonalized on $SRUSHU_t$ and $AONUSEQ_t$. $SRUSHU_t$ is the single-peril hurricane index in excess of the 1-Month T-Bill rate and

[6] Orthogonalization in the context of factor modeling has been proposed by Fama and French (1993).

$AONUSEQ_t$ is the single-peril earthquake index in excess of the 1-Month T-Bill rate.

From a different perspective we derive a model called "Ratings Model." Assuming that cat bond fund managers do not focus on the perils but on the ratings of cat bonds, we can use a cat bond index which only captures the performance of BB-rated cat bonds. A rotated market factor can then be interpreted as a factor capturing all better or worse rated cat bonds. Formally the *Ratings Model* is described as:

$$R_{p,t} - R_{f,t} = \alpha + \beta_{p,1} CATMKO3_t + \beta_{p,2} SRBBCAT_t + \epsilon_t, \tag{3}$$

where $CATMKO3_t$ is the excess return of the market factor orthogonalized on $SRBBCAT_t$, and $SRBBCAT_t$ is the return of the BB-rated cat bond index in excess of the 1-Month T-Bill rate. $SRBBCAT_t$ can be further unfolded into different bond risk components. Specifically, $SRBBCAT_t$ is the difference between a term component (i.e., a treasury index minus the risk free rate) plus a default component (i.e., a BB-rated corporate bond index minus a treasury index) and a "insurance (esoteric) risk premium" component (i.e., a BB-rated catastrophe bond index minus a BB-rated corporate bond index) which indicates whether cat bonds or corporate bonds earned a higher premium during a specific time period. The last component is insofar very interesting because if the no arbitrage condition holds, these indices should have the same return based on identical rating and maturity. However, their return is not identical at each point in time and, thus, if cat bond funds were able to time their exposure between cat bonds and corporate bonds they could still earn a premium despite the factor itself being indistinguishable from zero. Formally, the "Transformed Ratings Model" is defined as follows:

$$R_{p,t} - R_{f,t} = \alpha + \beta_{p,1} CATMKO1_t + \beta_{p,2} TERM3Y_t + \beta_{p,3} DEFCOR_t + \beta_{p,4} DEFCAT_t + \epsilon_t, \tag{4}$$

where $CATMKO1_t$ is the excess return of the market factor orthogonalized on $TERM3Y_t$, $DEFCOR_t$, and $DEFCAT_t$. $TERM3Y_t$ is return on bonds with maturity between one and three years over the risk free rate. $DEFCOR_t$ is the default risk of corporate bonds with maturity of one to three years over treasuries with maturity between one and three years. $DEFCAT_t$ is the default risk of cat bonds (whose maturity ranges between one and three years, see, e.g., Braun, 2016) over corporate bonds with maturity between one and three years. Technically, the *Ratings Model* is a performance evaluation model as it takes into account different risk components, starting with the risk of holding higher or lower rated cat bonds, and then transforms into a model which accounts for the risk of the term structure, default risk of corporate bonds, and default risk of cat bonds.[7] Finally, we augment all catastrophe factor models by an option factor, CHIBINARY, in the time-series regressions. This factor accounts for extreme downside risk that could be taken on through derivative instruments with a parametric exposure to Atlantic hurricanes.

4 Empirical results

In a first step, we present the risk and return characteristics for the different classifications and in comparison to other asset classes to shed further light on this relatively new and often unknown asset class. In a second step, we run style analyses (i.e., time-series regressions) using the asset allocation and traditional performance measurement models followed by the new cat bond factor models. In a last step we address the performance of the new cat bond factor models in the cross-section of cat bond funds.

4.1 Performance attribution of catastrophe bond funds

The performance of cat bond funds is unlike any other asset class in terms of risk and return. Over the last 14 years cat bond funds have earned an annual return of 5.47% on average while the aggregated volatility of these instruments is set at 2.32% and a minimum return of 3.46% occurred during a month. In comparison, during the the same period a similarly rated (i.e., BB) corporate bond index earned approx. 50% more at 8.11% p.a. than cat bond funds but at a price of a 260% higher volatility at 8.33% p.a. and a minimum return of 15.13% occurred during a month. Hedge funds, where many cat bond funds are classified, earned a similar rate as cat bond funds of 5.87% but also at a price of a 160% higher volatility at 6.06% and a minimum return of 6.84%. We also observe a slightly lower return earned by dead cat bond funds as well as by those categories seen as less risky such as "Fixed Income." Note that to obtain a more comprehensive picture of the risk-return characteristics, it is common to consider the maximum available time period for each fund (see, e.g., Chen et al., 2010). Owing to this fact, however, the results for the different fund categories must be interpreted with caution. Table 4 summarizes the return characteristics of cat bond funds and their comparison indices.

[7]Note that a complete combination of the two previously defined models into one (aside from over-fitting) is not useful as the factors from the *Perils Model* are located within the *Ratings Model* and vice versa. Thus, a combination of the models does not increase the explanatory power of the time-series.

Table 4: Return characteristics

Classification	Time Period	Obs.	Avg. Return (% p.a.)	Median (% p.a.)	Min. (% monthly return)	Max. (% monthly return)	Volatility (p.a.)	Skewness	Kurtosis
All funds	01/2001 - 12/2014	168	5.47	6.23	-3.46	2.12	2.32	-2.68	14.92
By Fund Category									
Alternative	07/2002 - 12/2014	150	5.84	6.41	-4.07	1.89	2.46	-2.50	15.48
Equity	09/2011 - 12/2014	40	6.39	5.34	-0.58	2.33	1.90	1.08	5.54
Fixed Income	06/2001 - 12/2014	163	4.01	4.32	-4.28	1.53	2.08	-3.68	25.90
Mixed Allocation	08/2005 - 12/2014	113	5.73	6.00	-2.70	1.75	2.05	-2.81	15.19
Specialty	01/2012 - 12/2014	36	5.20	4.64	-0.09	1.20	1.16	0.49	2.48
No category	01/2001 - 12/2014	168	6.32	7.89	-6.05	3.32	3.89	-2.87	16.58
By Current Status									
Live Funds	01/2001 - 12/2014	168	5.66	6.41	-3.53	2.23	2.53	-2.82	15.11
Dead Funds	07/2002 - 10/2013	136	4.76	5.55	-2.99	1.85	2.23	-1.99	10.30
Comparison Indices									
Cat Bond Fund Index	01/2006 - 12/2014	108	6.55	7.08	-3.94	1.60	2.15	-3.59	26.84
Hedge Fund Index	01/2001 - 12/2014	168	5.87	8.47	-6.84	5.15	6.06	-0.88	5.04
HY Corporate Bond Index	01/2001 - 12/2014	168	8.71	13.29	-15.91	12.10	10.18	-1.10	10.58
BB Corporate Bond Index	01/2001 - 12/2014	168	8.11	12.33	-15.13	7.59	8.33	-1.99	14.86

This table summarizes the returns characteristics of 55 catastrophe bond funds both aggregated ("All funds") and separated by category (i.e., the Bloomberg categories of "Alternative", "Equity", "Fixed Income", "Mixed Allocation", or "Specialty") and status (i.e., "Live" or "Dead"). The table reports the classification, the time period, the number of time-series observations, the annualized average return, annualized median return, the monthly minimum return, the monthly maximum return, the annualized volatility, skewness, and kurtosis from monthly returns. The table also shows indices from other benchmarks and related asset classes for the purpose of direct comparisons. The comparison indices include a cat bond fund index published by EurekaHedge for the time period January 2006 until December 2014, the fund weighted composite index for hedge funds by HFR, the high yield (HY) corporate bond performance index by Barclays, and the BB corporate bond performance index by Merrill Lynch. Note that nine funds do not have a fund category or any fund information but do have return information which are used in this analysis. The sample starts in January 2001 and ends in December 2014.

Table 5 dives further into the risk characteristics of cat bond funds and their comparison indices. We show these risk measures because of the fact that cat bonds should exhibit severe but rare downward movements from time to time which cannot be captured by a traditional standard deviation. Examining the downside volatility, we again observe a much lower result compared corporate bonds or hedge funds. Even the value-at-risk (VaR) is at 1.1% per month for cat bond funds compared to 4.93% for BB corporate bonds and 3.58% for hedge funds. More intriguing is the fact that the maximum drawdown from peak to bottom is merely 7.19% compared to 25.13% for BB corporate bonds and 21.42% for hedge funds. Thus, risk measures which also account for returns in the nominator, such as the Sharpe Ratio, the Sortino Ratio, the Excess Return on VaR, and the Calmar Ratio, are multiples for cat bonds funds of the values for hedge funds and corporate bonds.

Table 5: Risk characteristics

Classification	Time Period	Downside-Volatility (p.a.)	VaR (% per month)	Max. Draw-down (in %)	Sharpe Ratio (p.a.)	Sortino Ratio (p.a.)	Excess return on VaR	Calmar Ratio (p.a.)	% of positive months
All funds	01/2001 - 12/2014	1.57	1.10	7.19	1.69	2.50	0.30	0.55	89.29
By Fund Category									
Alternative	07/2002 - 12/2014	1.57	1.17	4.07	1.82	2.85	0.32	1.10	88.00
Equity	09/2011 - 12/2014	0.41	0.75	0.58	3.35	15.64	0.71	11.04	90.00
Fixed Income	06/2001 - 12/2014	1.55	1.08	4.41	1.22	1.65	0.20	0.58	87.73
Mixed Allocation	08/2005 - 12/2014	1.37	0.90	5.99	2.14	3.20	0.41	0.73	92.04
Specialty	01/2012 - 12/2014	0.06	0.35	0.09	4.47	81.19	1.24	57.53	91.67
No category	01/2001 - 12/2014	2.89	2.09	17.55	1.23	1.65	0.19	0.27	88.10
By Current Status									
Live Funds	01/2001 - 12/2014	1.77	1.23	9.09	1.62	2.33	0.28	0.45	90.48
Dead Funds	07/2002 - 10/2013	1.42	1.10	2.99	1.46	2.28	0.25	1.09	83.82
Comparison Indices									
Cat Bond Fund Index	01/2006 - 12/2014	1.39	0.90	3.94	2.47	3.83	0.49	1.35	92.59
Hedge Fund Index	01/2001 - 12/2014	3.92	3.58	21.42	0.71	1.10	0.10	0.20	66.67
HY Corporate Bond Index	01/2001 - 12/2014	6.90	6.12	33.31	0.70	1.04	0.10	0.22	70.83
BB Corporate Bond Index	01/2001 - 12/2014	5.90	4.93	25.13	0.79	1.11	0.11	0.26	72.62

This table summarizes the risk characteristics of 55 catastrophe bond funds both aggregated ("All funds") and separated by category (i.e., the Bloomberg categories of "Alternative", "Equity", "Fixed Income", "Mixed Allocation", or "Specialty") and status (i.e., "Live" or "Dead"). The table reports the classification, the time period, the annualized downside volatility, the monthly value-at-risk (VaR), the maximum drawdown, the annualized Sharpe ratio, the annualized Sortino ratio, the excess return on the value-at-risk, the annualized Calmar ratio, and the percentage of positive monthly returns over the sample period. The table also shows indices from other benchmarks and related asset classes for the purpose of direct comparisons. The comparison indices include a cat bond fund index published by EurekaHedge for the time period January 2006 until December 2014, the fund weighted composite index for hedge funds by HFR, the high yield (HY) corporate bond performance index by Barclays, and the BB corporate bond performance index by Merrill Lynch. Note that nine funds do not have a fund category or any fund information but do have return information which are used in this analysis. The sample starts in January 2001 and ends in December 2014.

4.2 Traditional factor models

We now run asset allocation models to identify a potential exposure of cat bonds funds towards certain asset classes in case they invest in other instruments than cat bonds. The dependent variable is the aggregated cat bond fund index in excess of the 1-Month T-Bill rate. We run all asset class factors in one model and also run three variations to account for the high correlation between certain asset class factor models. All asset class factors are excess returns.

Table 6: Asset class exposure

	(1)	(2)	(3)	(4)
MKTRF	-0.01	0.02*		
	(0.02)	(0.01)		
Treasury	-0.01	-0.00		0.03
	(0.05)	(0.03)		(0.04)
Municipal	0.04	0.05		0.05
	(0.03)	(0.04)		(0.03)
Corporate	-0.01	0.04	0.03	0.01
	(0.04)	(0.04)	(0.03)	(0.04)
Mortgage	0.11		0.09	
	(0.10)		(0.07)	
Convertible	0.03			0.04**
	(0.04)			(0.02)
Real Estate	0.02	0.01	0.02	0.01
	(0.05)	(0.05)	(0.05)	(0.05)
Hedge Fund	0.04		0.07**	
	(0.06)		(0.03)	
Commodity	-0.01	-0.00	-0.01	-0.00
	(0.01)	(0.01)	(0.01)	(0.01)
Constant	0.27***	0.30***	0.27***	0.29***
	(0.09)	(0.08)	(0.09)	(0.09)
Adj. R^2	0.01	0.02	0.03	0.02
Obs.	156	156	156	156

This table shows the coefficients of asset class factors on the excess return of the catastrophe bond fund index over the 1-Month T-Bill rate. The asset class factors are all monthly excess returns. Standard errors in parentheses are Newey-West (1987) corrected with lags of four. The analysis starts in January 2002 and ends in December 2014. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 6 shows the coefficients of the factors. Our first observation is the low adjusted R-square of not more than 3%. Our second observation is the high abnormal return, i.e., alpha of at least 0.27% per month. Due to multi-collinearity the full model does not result in any significant coefficients, however, the three variations show some weak exposure towards the equity market, convertible bonds, and hedge funds. Although these asset classes seem reasonable for a cat bond fund to be weakly invested in, we control for statistical artifacts by including the cat bond market factor and address this issue in Table 8. We also run the traditional performance measurement or risk factor models in Table 7.

Table 7: Risk factor models

	(1)	(2)	(3)	(4)
MKTRF	0.02*		0.02*	0.02*
	(0.01)		(0.01)	(0.01)
SMB	-0.00		-0.00	0.00
	(0.02)		(0.02)	(0.02)
HML	0.01		0.01	
	(0.02)		(0.02)	
TERM	0.03	-0.01		0.03
	(0.02)	(0.02)		(0.02)
DEF	0.04**			0.04**
	(0.02)			(0.02)
HYield		0.04***		
		(0.01)		
Mortgage		0.12		
		(0.10)		
MOM			-0.01	
			(0.01)	
PTFSBD				0.00
				(0.00)
PTFSFX				-0.00
				(0.00)
PTFSCOM				0.00*
				(0.00)
Constant	0.31***	0.28***	0.32***	0.31***
	(0.09)	(0.09)	(0.08)	(0.08)
Adj. R^2	0.01	0.04	0.00	0.01
Obs.	156	156	156	156

This table shows the coefficients of risk factors from established factor models on the excess return of the catastrophe bond fund index over the 1-Month T-Bill rate. The risk factors are all monthly excess returns. Standard errors in parentheses are Newey-West (1987) corrected with lags of four. The analysis starts in January 2002 and ends in December 2014. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

We find again some statistical significance despite the adjusted R-square not exceeding 4% and alpha being at the same level as in the case of the asset allocation model. Here again the equity market, DEF, HYield, and PTFSCOM are significant. When we control for all significant variables in Table 8 by including the cat bond market factor, we see that all other variables are statistically and economically equal to zero while the adjusted R-square jumps to 67% and alpha becomes insignificant suggesting that other asset classes are statistical artifacts.

Table 8: Control regressions

	(1)	(2)	(3)	(4)	(5)
CATMKT	0.71***	0.71***	0.72***	0.71***	0.70***
	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)
MKTRF	-0.00				
	(0.01)				
DEF		-0.00			
		(0.01)			
Convertible			-0.01		
			(0.01)		
HYield				-0.01	
				(0.01)	
PTFSCOM					-0.00
					(0.00)
Constant	-0.06	-0.06	-0.06	-0.06	-0.06
	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)
Adj. R^2	0.67	0.67	0.67	0.67	0.67
Obs.	156	156	156	156	156

This table shows the coefficients of asset class factors and risk factors from established factor models on the excess return of the catastrophe bond fund index over the 1-Month T-Bill rate. The asset class factors and risk factors are all monthly excess returns. Standard errors in parentheses are Newey-West (1987) corrected with lags of four. The analysis starts in January 2002 and ends in December 2014. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

4.3 New factor models

In the previous control regressions we already observed a highly significant value for the coefficient on the cat bond market factor with a high adjusted R-square and an insignificant intercept. Column (1) in Table 9 shows this benchmark model again without any other factors. The fact that the coefficient is 0.70 suggests that cat bond funds either are not fully invested in cat bonds and might hold some cash reserves or they do not hold a fully diversified basket of cat bonds but overweight cat bonds with higher attachment points, meaning less risk but also lower returns. Another explanation could be that cat bond funds are not always invested in cat bonds but when they do they fully engage in these instruments assuming it is the right time to invest and thus would try to time the market. Column (2) shows the *Ratings Model*. An economically and statistically weak coefficient for CATMKO1 indicates that the bulk of cat bond investments is in BB-rated cat bonds. The highly significant coefficients on DEFCAT shows that cat bonds are strongly preferred over corporate bonds which do not affect the performance of cat bond funds. Column (3) shows the *Perils Model*. This model slightly increases the adjusted R-square by three percentage points to 70% compared to the *CAT-CAPM*. We find that the majority of cat bond exposure in cat bond funds is not in U.S. single-peril hurricane or earthquake cat bonds but in multi-peril cat bonds around the globe as indicated by the high coefficients.

Table 9: Time-series regression of new factor models

	(1)	(2)	(3)	(4)	(5)	(6)
CATMKT	0.70***			0.69***		
	(0.10)			(0.09)		
CATMKO1		0.26*			0.24	
		(0.15)			(0.16)	
TERM3Y		0.65***			0.67***	
		(0.08)			(0.09)	
DEFCOR		0.60***			0.59***	
		(0.07)			(0.06)	
DEFCAT		0.60***			0.58***	
		(0.07)			(0.06)	
CATMKO2			0.89***			0.87***
			(0.13)			(0.12)
SRUSHU			0.33***			0.33***
			(0.03)			(0.03)
AONUSEQ			0.07**			0.07**
			(0.03)			(0.03)
CHIBINARY				-0.03***	-0.03***	-0.03***
				(0.00)	(0.00)	(0.00)
Constant	-0.06	0.01	-0.01	-0.07	-0.01	-0.02
	(0.09)	(0.06)	(0.06)	(0.07)	(0.04)	(0.04)
Adj. R^2	0.67	0.69	0.70	0.78	0.80	0.81
Obs.	156	156	156	156	156	156

This table shows the coefficients of the new risk factors on the excess return of the catastrophe bond fund index over the 1-Month T-Bill rate. The asset class factors and risk factors are all monthly excess returns. Standard errors in parentheses are Newey and West (1987) corrected with lags of four. The analysis starts in January 2002 and ends in December 2014. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Furthermore, single-peril earthquake exposure seems to play a minor role for cat bonds funds, possibly because of the additional expertise needed for such cat bonds. When we augment the *CAT-CAPM*, the *Ratings Model*, and the *Perils Model* by the option factor, CHIBINARY, we can significantly increase the explanatory power by ca. 11 percentage points in all specifications highlighting the exposure towards derivative instruments. The factor is statistically highly significant although the economic meaning is small because of the rare movements of the factor. Intercepts remain insignificant and the new factor tells us that there is no exposure towards non-BB rated cat bonds.

4.4 Predicting the cross-section

Having analyzed the time-series relation between the new factors and the aggregated cat bond fund index we now turn to the cross-section of cat bond funds. That is, we now want to find out if and why certain funds perform better or worse than other funds and whether our models can explain this outperformance. Before addressing each fund separately, we first examine the individual fund categories using the *Perils*

Model as benchmark model. Table 10 shows the excess return of the aggregate cat bond fund index, all fund categories as described in Section 3.1, and cat bond funds distinguished by their current status of being live or dead. We find that "Fixed Income" category is significantly underperforming its underlyings proven by the significantly negative constant, i.e., alpha. In contrast the weakly significant but economically large abnormal return for the "Mixed Allocation" category suggests some superior characteristic of these funds, either by investing in other asset classes which the name "Mixed Allocation" might suggest or by some superior cat bond evaluation. Furthermore, the explanatory power for the "Equity" category appears to be low with 28%. Again as the name suggests, a true exposure towards equity instruments could be the reason for that. Moreover, we observe a negative abnormal return for defunct funds. Thus, these funds are not only subject to mergers but in fact underperformed their underlyings.

Table 10: Subindices

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Fund category						Current status	
	All Funds	Alternative	Equity	Fixed Income	Mixed Alloc.	Specialty	No category	Live	Dead
CATMKO2	0.87***	0.89***	0.17	0.78***	0.40	0.17**	1.07***	0.94***	0.71***
	(0.12)	(0.11)	(0.19)	(0.15)	(0.27)	(0.07)	(0.35)	(0.16)	(0.07)
SRUSHU	0.33***	0.32***	0.37**	0.28***	0.20***	0.35***	0.44***	0.33***	0.30***
	(0.03)	(0.04)	(0.14)	(0.02)	(0.05)	(0.06)	(0.07)	(0.04)	(0.04)
AONUSEQ	0.07**	0.19***	-0.30*	0.25***	-0.02	0.01	-0.30***	0.01	0.20***
	(0.03)	(0.04)	(0.17)	(0.03)	(0.03)	(0.14)	(0.07)	(0.04)	(0.03)
CHIBINARY	-0.03***	-0.01***	-0.95	-0.01***	-0.03***	9.97	-0.06***	-0.03***	-0.01***
	(0.00)	(0.00)	(14.50)	(0.00)	(0.00)	(8.31)	(0.00)	(0.00)	(0.00)
Constant	-0.02	-0.02	-0.87	-0.17***	0.17*	12.59	0.07	0.00	-0.10***
	(0.04)	(0.04)	(18.14)	(0.04)	(0.09)	(10.40)	(0.13)	(0.06)	(0.04)
Adj. R^2	0.81	0.69	0.28	0.76	0.47	0.71	0.78	0.77	0.68
Obs.	156	150	40	156	113	36	156	156	136

This table shows the coefficients of the "Perils Model" augmented by the hurricane option factor. The dependent variable in column (1) is the excess return of the catastrophe bond fund index over the 1-Month T-Bill rate. The dependent variables in column (2) - (7) are excess returns of catastrophe bond funds distinguished by their respective fund category. The dependent variables in column (8) and (7) are excess returns for catastrophe bond funds distinguished by their current status (i.e, dead or live). The time period for the different excess return indices ranges between January 2002 and December 2014. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

We now address each fund separately. For that purpose, each fund must have at least 24 months of consecutive return data. Table 11 shows how many fund intercepts (alpha) estimated by the CAT-CAPM are significantly positive (+) or negative (-) at the 10%-level and how many are insignificant. The majority of funds, that is 59.52%, exhibits an insignificant intercept meaning the model captures most of the abnormal returns. This also applies to the few significantly negative funds, that is 14.29%. The negative abnormal return can be the result of too high fees which cannot earn a higher rate of return or it can be the result of bad market timing. Whatever the reason, the CAT-CAPM indicates an insufficient performance. However, it is not able to explain the 26.19% of cat funds which earn a superior abnormal performance. The question is thus whether the other two models are able to do the job.

Table 11: Time series regressions of individual funds on *CAT-CAPM*

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Fund category						Current status	
	All Funds	Alternative	Equity	Fixed Income	Mixed Alloc.	Specialty	No category	Live	Dead
Alpha distr.									
+	26.19%	31.25%	50.00%	0.00%	40.00%	100.00%	28.57%	34.38%	0.00%
0	59.52%	68.75%	50.00%	54.55%	60.00%	0.00%	71.43%	50.00%	90.00%
−	14.29%	0.00%	0.00%	45.45%	0.00%	0.00%	0.00%	15.63%	10.00%
No. of funds	42	16	2	11	5	1	7	32	10

This table shows the distribution of alphas (i.e., the constant) coefficients of the "CAT-CAPM" on excess returns of individual catastrophe bond funds. To be included in the individual fund regression a fund must have at least 24 months of consecutive return data. Alphas are considered significantly positive (+) or negative (−) if they are significant at the 10%-level. Alphas are considered insignificant (0) if they are significant above the 10%-level. The number of funds in each category is reported in the last row of the table. The time period for each individual fund ranges between January 2002 and December 2014.

We, thus, run the *Ratings Model* first. Table 12 shows how many fund intercepts estimated by the *Ratings Model* are significantly positive (+) or negative (-) at the 10%-level and how many are insignificant. Surprisingly, the model identifies slightly more significantly positive intercepts and less significantly negative intercepts. The reason for this behavior lies in the statistical features of DEFCAT and DEFCOR which are highly correlated with each other and thus affect the evaluation abilities of the entire model for individual funds. Hence, we focus on the *Perils Model* to analyze the cross-section.

Table 12: Time series regressions of individual funds on *Ratings Model*

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Fund category						Current status	
	All Funds	Alternative	Equity	Fixed Income	Mixed Alloc.	Specialty	No category	Live	Dead
Alpha distr.									
+	28.57%	25.00%	50.00%	9.09%	60.00%	100.00%	28.57%	34.38%	10.00%
0	61.90%	75.00%	50.00%	54.55%	40.00%	0.00%	71.43%	56.25%	80.00%
−	9.52%	0.00%	0.00%	36.36%	0.00%	0.00%	0.00%	9.38%	10.00%
No. of funds	42	16	2	11	5	1	7	32	10

This table shows the distribution of alphas (i.e., the constant) coefficients of the "Ratings Model" on excess returns of individual catastrophe bond funds. To be included in the individual fund regression a fund must have at least 24 months of consecutive return data. Alphas are considered significantly positive (+) or negative (−) if they are significant at the 10%-level. Alphas are considered insignificant (0) if they are significant above the 10%-level. The number of funds in each category is reported in the last row of the table. The time period for each individual fund ranges between January 2002 and December 2014.

The high explanatory power in the time-series and the low correlation of the factors with each other results in a better performance than the *CAT-CAPM*. Table 13 shows the results. We now observe that the number of funds with significantly negative intercepts almost doubles from 14.29% for the *CAT-CAPM* to 26.19% for the *Perils Model* which shows that certain funds were underperforming the combination of the three factors. Interestingly though, the model is not able to capture the 26.19% of funds with significantly positive abnormal returns. Apparently, more than one quarter of all funds are able to consistently outperform the market for cat bonds.

Table 13: Time series regressions of individual funds on *Perils Model*

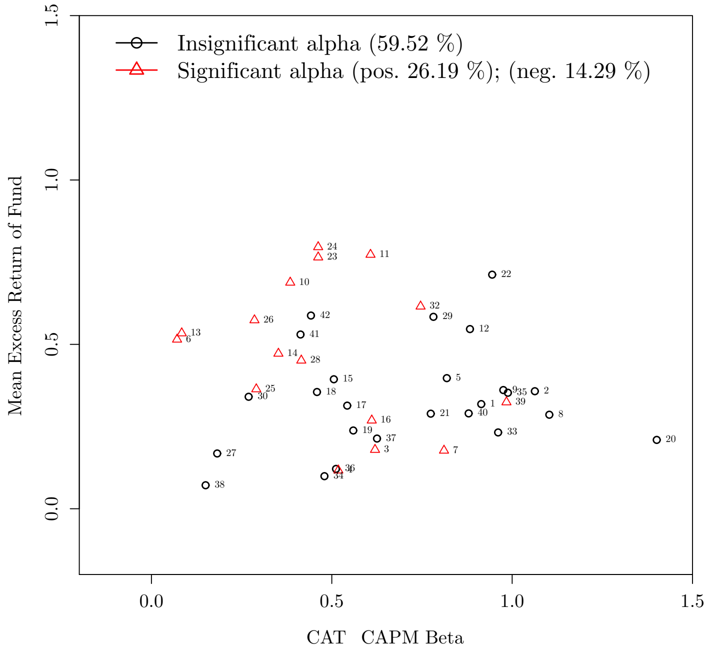
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Fund category						Current status	
	All Funds	Alternative	Equity	Fixed Income	Mixed Alloc.	Specialty	No category	Live	Dead
Alpha distr.									
+	26.19%	31.25%	50.00%	0.00%	40.00%	100.00%	28.57%	34.38%	0.00%
0	47.62%	43.75%	50.00%	36.36%	60.00%	0.00%	71.43%	43.75%	60.00%
−	26.19%	25.00%	0.00%	63.64%	0.00%	0.00%	0.00%	21.88%	40.00%
No. of funds	42	16	2	11	5	1	7	32	10

This table shows the distribution of alphas (i.e., the constant) coefficients of the "Perils Model" on excess returns of individual catastrophe bond funds. To be included in the individual fund regression a fund must have at least 24 months of consecutive return data. Alphas are considered significantly positive (+) or negative (−) if they are significant at the 10%-level. Alphas are considered insignificant (0) if they are significant above the 10%-level. The number of funds in each category is reported in the last row of the table. The time period for each individual fund ranges between January 2002 and December 2014.

To further illustrate these results we start by plotting the actual mean excess returns of 42 catastrophe bond funds against their cat bond market beta estimated by the *CAT-CAPM* in Figure 2. This graph tells us that if cat bond funds only invest in a diversified basket of cat bonds, their returns should be higher the larger the beta, that is, there should be a linear relationship between fund beta and return.[8] Most of the funds have a beta between 0.10 and 1.00 meaning that ca. 10% to 100% of their assets are invested in cat bonds. Three funds, however, have a beta larger than 1.00 meaning that there are funds who use leverage to increase their exposure towards cat bonds or go for lower, that is riskier, cat bond layers. Interestingly though, their returns are not larger than peers with lower betas. Moreover, the majority of funds with significant alphas have a beta exposure below 0.62. A reason for that could be either market timing or allocations to other asset classes or other ILS including life insurance instruments. Figure 3 illustrates these results by plotting the actual mean excess returns against the mean excess return predicted by each model. If no abnormal returns would exist, each fund (i.e., circle or triangle) would be on the dotted 45-degree line. Both in the *CAT-CAPM* graph and in the *Ratings Model* graph, several funds far away from the 45-degree line are insignificant while the *Ratings Model* sometimes even identifies funds close to the 45-degree line as significant.

[8]The following interpretation, must be seen cautiously, because the funds operate during different periods in time. Thus, even if a higher beta results in higher returns, changing market returns can impair the linear relationship.

Figure 2: CAT-CAPM beta representation

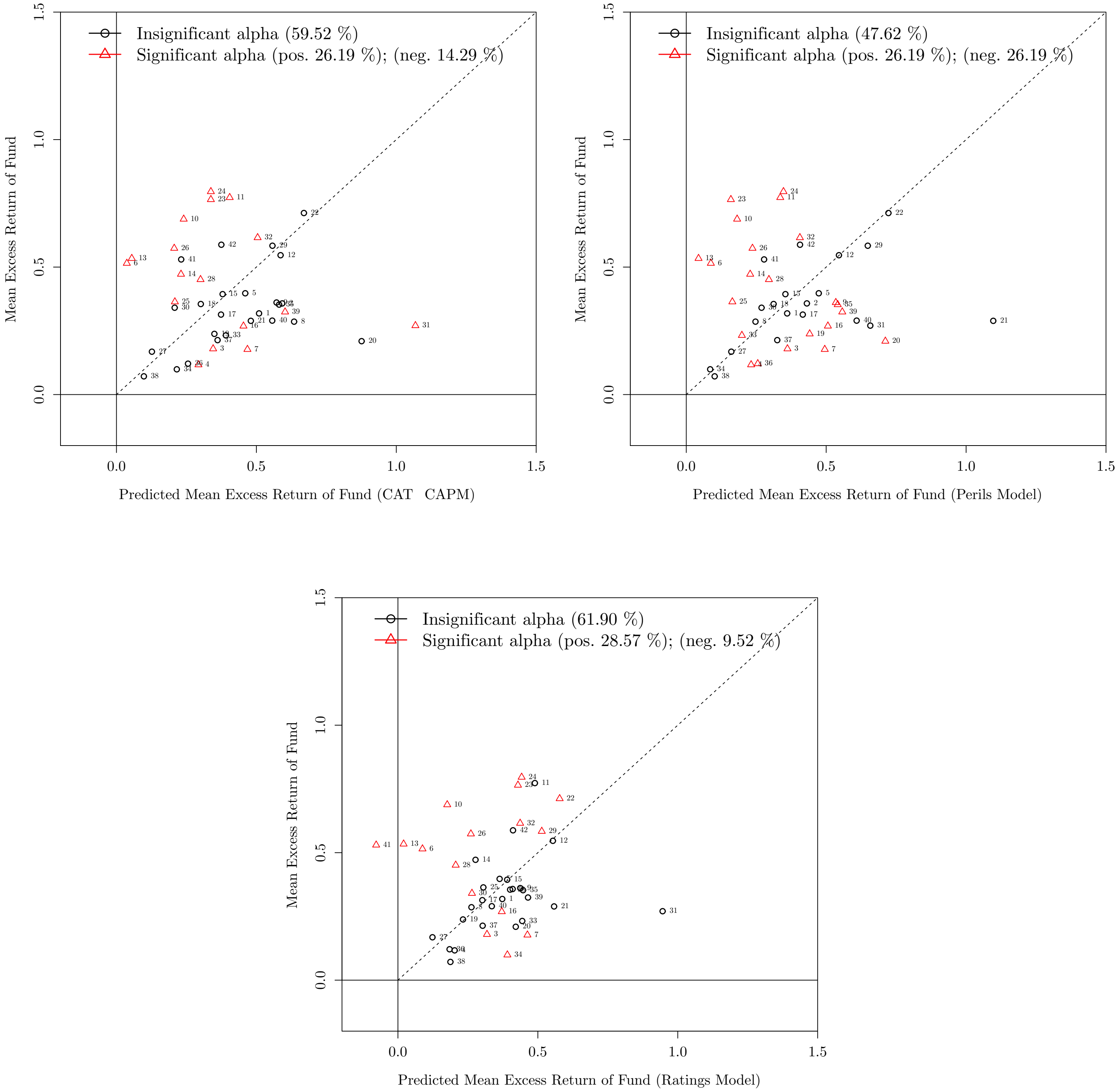


This figure illustrates the actual mean excess returns of 42 catastrophe bond funds against their cat bond market beta estimated by the "CAT-CAPM." Black circles indicate insignificant alpha values. Red triangles indicate significant alphas at the 10%-level. The legend on top of each graph highlights the percentage of insignificant, significantly positive, and significantly negative alphas predicted by the respective model.

Particularly the Perils Model draws a relatively concise picture with many funds below the 45-degree line being significantly negative. The only exceptions to this rule are fund 21, 31, and 40 which show insignificant alphas despite being far away from the 45-degree line. However, this is the result of very short return histories in the case of fund 31 and 40 resulting in weak statistical power to prove a significant intercept. Fund 21, in contrast shows a very large standard deviation compared to all other cat bond funds and thus being further off compared to its peers.

Funds with an abnormal positive performance are much more consistent in the graphs for the *CAT-CAPM* and the *Perils-Model* above the 45-degree line. Merely fund 41 and 42 deviate and are insignificant which is again the result of very short return histories. Overall, we conclude that there is an outperformance by more than one quarter of all cat bond funds which cannot even be explained by our new factor models.

Figure 3: Predicting the Cross-Section of Catastrophe Bond Funds



This figure illustrates the actual mean excess returns of 42 catastrophe bond funds and their predicted mean excess returns by the "CAT-CAPM" (upper left), the "Perils Model" (upper right), and the "Ratings Model" (bottom), respectively. Black circles indicate insignificant alpha values. Red triangles indicate significant alphas at the 10%-level. The legend on top of each graph highlights the percentage of insignificant, significantly positive, and significantly negative alphas predicted by the respective model.

5 Robustness

In robustness tests we analyze the performance of the augmented *Perils Model* during different time periods and how well other indices with exposure to natural catastrophes can be explained.

5.1 Subperiods

We separate the period January 2002 until December 2014 into three equally long time periods and run the augmented *Perils Model* against the excess return of the aggregate cat bond fund index. Furthermore, we control for potentially challenging time periods on cat bond funds including Hurricane Katrina and the Financial Crisis of 2008. Table 14 shows the results for the different subperiods.

Our first finding is that the augmented *Perils Model* performs very well throughout all time periods with adjusted R-squares between 76% and 85%. The orthogonalized cat bond market factor, CATMKO2, as well as the single-peril hurricane factor, SRUSHU, are highly significant at all times meaning that the majority of funds is constantly invested in multi-peril risks and single-peril hurricane risk. However, the earthquake factor, AONUSEQ, is only significant in the time period May 2006 to August 2010. Two reasons could explain this result. First, earthquake risk is often combined with other risks, e.g. hurricanes, and thus is comprised in the multi-peril category. Second, AONUSEQ only captures U.S. earthquakes, yet many earthquake cat bonds additionally securitize Canadian, or Japanese earthquakes, which are not included in AONUSEQ. The period May 2006 to August 2010 was the period with the strongest issuance activity for U.S. and specifically Californian earthquake cat bonds. Furthermore, CHIBINARY is only significant in the first period as it captures the initial effect of Hurricane Katrina but is insignificant in other periods. Including a dummy variable taking the value of one for the period August 2005 to December 2005 and zero else shows, however, that there are still effects in the aftermath of hurricane which neither the Perils Model nor the augmented CHIBINARY factor are able to capture. The often proclaimed argument that ILS and cat bond funds provide uncorrelated returns with the rest of the market can be corroborated on an aggregate basis. That is, including a dummy variable taking the value of one for the period most affected by the Financial Crisis - September 2008 to June 2009 - and zero else, shows an insignificant coefficient for the dummy variable.

Table 14: Subperiods

	(1) 01/2002-04/2006	(2) 05/2006-08/2010	(3) 09/2010-12/2014	(4) Hurricane Katrina	(5) Financial Crisis
CATMKO2	1.12***	0.46***	0.76***	0.75***	0.87***
	(0.07)	(0.06)	(0.16)	(0.12)	(0.12)
SRUSHU	0.44***	0.31***	0.32***	0.32***	0.33***
	(0.07)	(0.05)	(0.05)	(0.03)	(0.03)
AONUSEQ	0.38	0.05*	0.14	0.06**	0.08***
	(0.34)	(0.03)	(0.17)	(0.03)	(0.03)
CHIBINARY	-0.03***	0.07	13.95	-0.02***	-0.03***
	(0.00)	(0.19)	(11.19)	(0.00)	(0.00)
Katrina				-0.87***	
				(0.18)	
Financial Crisis					0.11
					(0.09)
Constant	-0.22	0.25	17.46	0.03	-0.04
	(0.15)	(0.28)	(13.97)	(0.04)	(0.05)
Adj. R^2	0.85	0.76	0.82	0.85	0.81
Obs.	52	52	52	156	156

This table shows the coefficients of the "Perils Model" augmented by the hurricane option factor and accounting for different time periods and events. The dependent variable is the excess return of the catastrophe bond fund index over the 1-Month T-Bill rate. Column (1) - (3) show the results for time periods January 2002 until April 2006, May 2006 until August 2010, and September 2010 until December 2014, respectively. Column 4 includes a dummy for the time period affected by Hurricane Katrina (with the time period August 2005 until December 2005 being defined as one and zero else). Column 5 includes a dummy for the time period affected by the Financial Crisis (with the time period September 2008 until June 2009 being defined as one and zero else). *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

5.2 Out-of-sample tests

In this part, we are interested how well our augmented *Perils Model* and *Ratings Model* perform on other indices related to the securitization of natural catastrophes. The first index is the Eurekahedge index which also tracks the aggregate performance of cat bond funds. Hence, we expect that our model should perform as good as on our proprietary aggregate cat bond fund index. The second index is the Mercury investible Catastrophe Risk Index, also known as MiCRIX, which tracks the performance of a diversified portfolio of peak peril industry loss warranties (ILWs).[9] In contrast to cat bonds ILWs are uncollateralized and unfunded double-trigger contracts, whose main trigger relies on an insurance industry loss index.[10] Both indices are in excess of the 1-Month T-Bill rate. Results are reported in Table 15 and indicate that, as expected, the Eurekahedge index can be well described by either model with adjusted R-squares of 77% for the *Perils Model* and 74% for the *Ratings Model*. In contrast, ILWs represented by the MiCRIX can be less explained by the cat bond fund models with adjusted R-squares of 59% and 58%, respectively. This suggests that the pricing of cat bonds has some effect on ILWs, yet

[9]The Eurekahedge index and the MiCRIX are, however, shorter in return history and start both in January 2006.
[10]For a detailed discussion of ILWs and catastrophe swaps, refer to Braun (2011).

other effects are at play. One explanation could be that insurance companies focus on other regions or have a lower exposure than cat bonds.

Table 15: Out-of-sample indices

	(1)	(2)	(3)	(4)
	Eurekahedge	Eurekahedge	Micrex	MICREX
CATMKO1		0.35		0.85
		(0.24)		(1.15)
TERM3Y		0.63***		1.96***
		(0.13)		(0.55)
DEFCOR		0.54***		1.66***
		(0.10)		(0.41)
DEFCAT		0.55***		1.94***
		(0.11)		(0.45)
CHIBINARY	-0.12	-0.10	0.11	0.58
	(0.24)	(0.24)	(1.04)	(0.88)
CATMKO2	0.83***		3.10***	
	(0.18)		(0.76)	
SRUSHU	0.27***		0.90***	
	(0.03)		(0.19)	
AONUSEQ	0.18***		-0.00	
	(0.02)		(0.22)	
Constant	-0.12	-0.07	-0.25	0.41
	(0.32)	(0.32)	(1.55)	(1.42)
Adj. R^2	0.77	0.74	0.59	0.58
Obs.	108	108	108	108

This table shows the coefficients of the "Perils Model" augmented by the hurricane option factor and the "Ratings Model" augmented by the hurricane option factor. The dependent variable in Column (1) and (2) is the excess return of the Eurekahedge catastrophe bond fund index over the 1-Month T-Bill rate. The dependent variable in Column (3) and (4) is the excess return of the Mercury investible Catastrophe Risk Index (MiCRIX) over the 1-Month T-Bill rate. Standard errors in parentheses are Newey-West (1987) corrected with lags of four. The indices start in January 2006 and end in December 2014. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

6 Conclusion

A better understanding of catastrophe funds is crucial for investors to make sophisticated investment decisions. This can be proven to be difficult due to the limited information by some of the cat bond funds. Using the first comprehensive dataset on cat bond funds, this paper tried to understand the performance features of cat bonds funds in comparison to other asset classes and to understand the key performance drivers of this innovative asset class. We show that cat bond funds are the highest performing asset class based on a battery of risk measures including the Sharpe Ratio, the Sortino Ratio, the Excess Return on VaR, or the Calmar Ratio. Cat bond funds are also consistently delivering positive return on an aggregate basis in ca. 90% of all analyzed months compared to 67% during the same period for hedge funds. We also show that single-peril hurricane, single-peril earthquake and multi-peril risks are driving the performance for ca. three quarters of all cat bond funds. Vice versa, one quarter of all cat bond funds is able to consistently generate significant alphas, even under the new model setting. Our findings may help to promote a better understanding of the main return drivers of cat bond funds. Hence, they should be relevant to risk managers and investors alike. We hope to contribute to the transparency of cat bond funds in order to support the further growth of this segment in the capital market.

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