UNIVERSITY OF GOTHENBURG
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# CATASTROPHE BONDS

*An investment analysis of their performance and diversification benefits*

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# Abstract

This thesis employs total return indices to investigate if catastrophe bonds are zero-beta assets and how they have performed compared to other assets. We conduct time series regressions and conclude that catastrophe bond returns are correlated with both the return of the equity- and the high yield corporate bond market during the subprime financial crisis, but find no significant correlation after the crisis. We include a proxy for risk aversion and find that investors' level of risk aversion affects the correlation during the crisis, something that previous researchers have discussed theoretically but not shown statistically. Using Sharpe ratios, we examine the risk-adjusted return of catastrophe bonds and show that catastrophe bonds noticeably out-performed the equities and the high yield corporate bonds, both during and after the crisis. The high risk-adjusted return, in combination with the low correlation with the other financial markets, make catastrophe bonds an attractive asset to investors.

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# Table of contents

**1. Introduction** ..... **2**
1.1 Background ..... 2
1.2 Literature review ..... 3
1.3 Aim and hypotheses ..... 4
1.4 Structure and delimitations ..... 5
**2. Theoretical framework** ..... **5**
2.1 Introduction to catastrophe bonds ..... 5
2.2 Pricing and trading of catastrophe bonds ..... 6
2.3 Catastrophe bond market development after the subprime crisis ..... 7
**3. Method** ..... **8**
3.1 Data ..... 8
3.2 Control variables ..... 9
3.2.1 Time and seasonal trends ..... 9
3.2.2 Risk-free interest rate ..... 10
3.2.3 Risk aversion ..... 11
3.3 Serial correlation and heteroscedasticity ..... 12
3.4 Models ..... 13
3.4.1 Correlation ..... 13
3.4.2 Risk-adjusted return ..... 14
3.5 Descriptive statistics ..... 16
**4. Results** ..... **18**
4.1 Correlation during the crisis ..... 18
4.2 Correlation after the crisis ..... 20
4.3 Risk-adjusted return ..... 21
**5. Analysis** ..... **24**
5.1 Crisis period 2007-2009 ..... 24
5.2 Post crisis period 2010-2017 ..... 26
5.3 Risk-adjusted return total period 2007-2017 ..... 28
**6. Future research** ..... **28**
**7. Robustness** ..... **28**
7.1 Endogeneity and causality ..... 28
7.2 Risk-free rate proxy ..... 29
7.3 Sharpe ratio ..... 30
**8. Conclusion** ..... **31**
**References** ..... **32**

# 1. Introduction

## 1.1 Background

The event of a natural disaster causes huge losses both for the people affected and for the insurance companies involved. To enable insurance companies to protect themselves from such losses, reinsurance companies play an important role in the insurance business. During the 1990s, fueled by the devastation of Hurricane Andrew in Florida, a market for insurance-linked securities (ILS) started to develop in addition to traditional reinsurance, and this market has thrived since (Kish, 2016).

Catastrophe bonds (Cat bonds) have been the most successful in terms of volume traded (Cummins & Weiss, 2009). The first Cat bond was issued by Hannover Re, today Swiss Reinsurance Company (Swiss Re), in 1994. An initial definition of a Cat bond can be quoted from Kish (2016) as *"..a debt obligation in which the interest (coupon payments) and the return of principal are tied to the payoff requirements of an insurance company."* (Kish, 2016). When insurance claims increase due to a catastrophic event, the coupons and principal to the investor of a Cat bond covering such an event will be lost fully or to some extent. In short, Cat bonds offer to transfer the risk of natural and man-made disasters from insurance companies to investors in the capital market.

An important feature of Cat bonds mentioned in the literature (e.g. Bantwal & Kunreuther (2000), Cummins & Weiss (2009) and Kish (2016)) is that these bonds have zero to very low correlation with other investments such as stocks or corporate bonds. The low correlation (i.e. beta) increases the attractiveness of Cat bonds in portfolio diversification.

The state of the economy has no influence on the occurrence of natural disasters. Reversely, a study by Wang & Kutan (2013) show that natural disasters do not seem to significantly affect stock market returns. In a rational perspective this would suggest that premiums of Cat bonds should be uncorrelated with returns of other investments within the capital market and fit under the description zero-beta assets. If we instead assume that investors are not entirely rational, there might be reasons to believe that Cat bonds are correlated with the market. Since Cat bonds are considered high risk instruments, risk aversion as well as loss aversion of the investors might play an important role in the decision whether to include Cat bonds in a portfolio; such psychological factors can in turn be dependent of the economic cycle and create a link between Cat bonds and other asset classes that initially seem counterintuitive.

## 1.2 Literature review

Previous research on Cat bonds has been conducted during the late 20th century and early 21st century and primarily focuses on the supply side of the bonds (i.e. from the insurance companies' viewpoint). From an investor's perspective, as this thesis concerns, Bantwal & Kunreuther (2000) provide early work in which they try to explain why Cat bond premiums are higher than traditional financial theory predicts. By studying investors' behavior they conclude that premiums are high not only because of risk aversion but also because of loss aversion, ambiguity aversion and initial fixed costs of education. They propose simulations and standardization within the Cat bond market for it to fully develop. Similar to the purpose of Bantwal & Kunreuther's work, Barrieu & Loubergé (2009) aim to explain why the global Cat bond market is so small.

Cummins and Weiss (2009) put insurance linked securities (ILS), such as Cat bonds, in a historical context and provide an explanation of the specifics of such instruments. They test the correlation between Cat bonds and other asset classes over the period 2002 to 2008 and conclude that the correlation is almost zero over the years before the crisis and significantly different from zero during the subprime crisis. Further research within this field was conducted by Gürtler, Hibbeln & Winkelvos (2016), who studied the effect of financial crisis and natural disasters on Cat bond premiums and established that under such circumstances there is a positive relationship between Cat bond- and U.S. corporate bond premiums.

Wattman & Feig (2008) provide information about how the credit market has influenced the Cat bond market after 2007. Another more recent article, written from an investor's point of view, is that of Kish (2016), who starts off by identifying the risks of investing in the Cat bond market and continues by comparing returns from Cat bonds to those of corporate bonds. Kish concludes that the returns generated by Cat bonds offsets the risk of the investment. Similar to what Cummins and Weiss (2009) claim, he states that diversification is a beneficial feature of Cat bonds.

As stated above, the hypothesis of Cat bonds being zero-beta assets has in previous literature been rejected in a period of financial crisis but supported under non-crisis conditions by Cummins and Weiss (2009) who test the hypothesis under non-crisis conditions over the period 2002-2007. During their period of focus, the Cat bond market was in an early stage and the subprime crisis that followed has since then shaped the market (Wattman & Fieg, 2008). Additionally, the number of outstanding securities on the ILS market has increased substantially since 2002 and peaked as late as 2016 (ARTEMIS, 2017). There is a lack of research that focuses on testing the correlation between Cat bonds and other securities in the conditions of the post-crisis era, which is one of the contributions of this thesis.

## 1.3 Aim and hypotheses

The aim of this thesis is to investigate the value of Cat bonds to investors. When evaluating an investment, the return is weighed against the risk of the investment. Two main risks are usually considered: the systematic and idiosyncratic risk. The systematic risk is often referred to as the market risk, measured by the beta of an asset. Cat bonds are presented as an instrument with little or no correlation with the market (zero or low beta), though this hypothesis has been disproven during the financial crisis and has not been tested after the crisis. If the statement that Cat bonds are zero- or low-beta instruments can be strengthened further by investigating this correlation not only during the subprime crisis but also after the crisis, this would suggest that Cat bonds can offer a relevant source of diversification to investors. The main focus of this thesis is therefore to examine the systematic risk and answer the question if Cat bonds are zero-beta assets. The second question we research is if Cat bonds have outperformed the equity- and the high yield corporate bond market seen to risk-adjusted returns; thereby taking into account the idiosyncratic risk (asset-specific risk). To achieve the aim described we test the following four hypotheses.

Correlation null hypotheses:

*$H_1$: Cat bond returns are not correlated with stock market returns.*

*$H_2$: Cat bond returns are not correlated with corporate bond market returns.*

Risk-adjusted return null hypotheses:

*$H_3$: The risk-adjusted return in the Cat bond market is lower or equal to the return in the stock market.*

*$H_4$: The risk-adjusted return in the Cat bond market is lower or equal to the return in the corporate bond market.*

We investigate these hypotheses during a time of both the subprime crisis 2007-2009 and post-crisis market conditions 2010-2017, whereas a lot of previous researchers, as mentioned above, have focused only on the crisis and the pre-crisis period. Another contribution of this thesis is that we include a proxy for risk aversion in the regression when testing the correlation hypotheses. By this we aim to explain if changes in risk appetite might affect the correlation in different periods.

### 1.4 Structure and delimitations

The second section of this thesis covers the theoretical framework including the structure of Cat bonds, an explanatory part of how Cat bonds are priced and traded and how the market has developed over the years of 2009 to 2016. After the theoretical section an empirical study follows where the method is described and secondary data is used to test the hypotheses. The results are presented in section four. In section five we analyze the results, in section six we propose future research topics and in section seven we discuss the robustness of the method. Lastly, in section 8, we state our conclusions.

The scope of the study is limited to the comparison of Cat bonds with two other asset classes: stocks and high yield corporate bonds. We use the empirical study to test the hypotheses in a global perspective by using proxies that is presumed to reflect the global market, even though the majority of the Cat bonds represented in the global index is issued in the U.S. The time period of interest is 2007 to 2017. The period is divided into two parts, where the first part covers the crisis and the second part covers the post-crisis conditions of the market.

A risk connected to Cat bonds that is often discussed in the literature is liquidity risk, which would be an interesting aspect to study in the post-crisis period because of the rising trading volumes in the Cat bond market. In the empirical study, we use an index as a proxy for the Cat bond market and do not have information about the volumes traded for each individual bond within the index, therefore an analysis of liquidity risks is outside the scope of this thesis.

## 2. Theoretical Framework

### 2.1 Introduction to catastrophe bonds

The payments (i.e. coupons and principal) of a Cat bond are tied to specific events called triggers, which are specified in the bond indenture. (Cummins, 2008) In case of a triggering event some or all of the payments to the investor are lost. The triggers differ between different bonds and are typically one of the five types: parametric, modeled loss, industry loss index, indemnity and hybrid. For parametric triggers the bond is triggered if an objective parameter is met, such as wind-speed of a hurricane. Modeled loss, industry loss index and indemnity triggers are connected to modeled expected losses of the event, actual industry losses and actual insurance company losses respectively. Hybrid refers to a combination of the above mentioned triggers. (FINRA, 2013) In 2012 the most common triggers were industry loss index (40 %) and indemnity (37 %). (Swiss Re, 2012)

Cat bonds are typically set up by initially forming a single purpose reinsurer (SPR). The SPR issues the bond and the proceeds are invested in safe investments such as government bonds or AAA rated corporate bonds in a trust account. The fixed returns in the trust account are usually swapped for floating returns to reduce interest rate risk. The funds in the trust will be released to the insurance company in case the bond is triggered, helping the insurer to pay claims arising from the catastrophic event. In most Cat bonds the principal will be fully lost in case of a triggering event, but some Cat bond issues have included principal protected tranches where the principal is guaranteed and the only returns affected by the triggering event are the coupon payments. (Cummins, 2008)

## 2.2 Pricing and trading of catastrophe bonds

The vast majority of the Cat bonds outstanding are priced with a spread (premium) over a three month floating interest rate such as EURIBOR, LIBOR or U.S Treasury bills, where the U.S Treasury bill is the most commonly used. (Kish, 2016) Like other bonds, the yield to maturity of a Cat bond is the return from buying a bond, holding it until maturity and receiving the principal, assuming you can reinvest any coupon payments at the same rate. The yield has an inverse relationship with the price of the bond, meaning that lower price equals higher yield. (Berk & DeMarzo, 2011, p. 219) According to neo-classic economic theory, investors are assumed to be rational. In a Cat bond pricing perspective this rational behavior means that the yield is determined by two factors: the underlying risk-free rate and the investors' required return for bearing the risk of default, which is determined by the risk of the occurrence of a natural disaster and the investors' risk aversion.

In the evolutionary state of Cat bonds, many researchers were puzzled by the high premiums since capital market theory suggest that zero-beta assets should be priced similar to risk-free rates. (Cummins & Weiss, 2009) Early research (e.g. Bantwal & Kunreuther, 2000, and Froot, 2001) give market imperfections, market power of reinsurance companies and behavioral economic aspects as possible explanations to why this fails. Since then, as the market has evolved spreads have declined, but Cummins & Weiss (2009) state that Cat bond yields are still unlikely to converge to the risk-free rate. Kish (2016) introduces several aspects of risk associated with investing in Cat bonds that help understand the high premiums that investors demand. Besides the tail risk – a small possibility of a huge loss – there is a lack of liquidity in the Cat bond market. There are also modeling risks since there are no perfect models to simulate events and counterparty risk since the associated insurance firm can go into financial distress. (Kish, 2016)

Cat bonds are normally issued under SEC 144A regulations which means that only qualified institutional buyers (QIBs) are allowed to buy these securities within the first year. Most Cat bonds have two- to five year maturities and after the first year they can be traded in the secondary market. (Kish, 2016)

## 2.3 Catastrophe bond market development after the subprime crisis

One major development in the total Cat bond and ILS market after the subprime crisis is that the volume of outstanding securities has continued to increase substantially. The volume outstanding in 2009 and 2017 was $ 13 905 million and $ 25 752 million respectively, with a peak in 2016 of $ 26 820 million. (ARTEMIS, 2017) Even shortly after the crisis, in late 2008, the pricing, stability and volumes traded of Cat bonds compared to other debt instruments indicated that investors were not put off by the crisis, but instead found value in the ILS asset class. (Wattman & Feig, 2008)

The crisis revealed some possible drawbacks in the structure of Cat bonds. For instance, some SPRs had Lehman Brothers, which became bankrupt in 2008, as their interest rate swap counterparty. This called for increased transparency and restrictions in the Cat bond market. (Cummins & Weiss, 2009) The structure of Cat bonds has since then been refined. Most of the Cat bonds are now rated by one or more rating agency, where the rating is based on risk modeling and losses connected to the specific catastrophe. In addition to this improvement, the focus after the crisis has been to reduce the exogenous risks, such as the above mentioned swap counterparty risk but also risks connected to the trust account held by the SPR. The swap counterparty was earlier obligated to make a whole for potential losses only at maturity, these obligations have been harshened and the counterparty now has to maintain market value of their investments at all times. The different asset classes that are permitted as a collateral for the issuing SPR is reduced, for example CDOs (collateralized debt obligations) are no longer allowed. (Wattman & Feig, 2008) In conclusion, the market has grown both bigger and more mature since the financial crisis.

In addition to changes in the Cat bond market after the subprime crisis, the overall capital market has also had some abnormal features in this period. The low interest rate environment where several risk-free rates show values below zero is specifically interesting. This could lead investors to search for higher yields from riskier securities, consequently pushing risk premiums down. However, according to a trend observed by Bloomberg in July 2016 investors in the low interest rate environment chose to hold assets with longer maturity, thereby exposing themselves to a higher duration risk instead of trying to reduce the interest rate risk by investing in short term assets with a higher credit risk. (Alloway, 2016)

# 3. Method

## 3.1 Data

The total sample we use consists of 534 observations of weekly returns from January 2007 until March 2017 of the Swiss Re Global Cat Bond Total Return Index (denoted CAT), the S&P 500 Index (denoted SPX) and the BofA Merrill Lynch US High Yield BB Effective Yield Index (denoted CorpBond). Weekly data is used since Swiss Re publishes the Cat bond index price data on a weekly basis. The data is divided into two periods: one during the subprime crisis and one after the crisis. The period of the subprime crisis is here defined as 2007.01.01 to 2009.12.31, with 155 observations. The subsequent period is what we refer to as the post-crisis period, from 2010.01.01 to 2017.03.30 with 379 observations. There are 30 missing values during the total period in the variable CorpBond, nine (9) in crisis (table 1) and 21 in post-crisis (table 2). This leaves us with a total of 504 observations, 146 in crisis and 358 in post-crisis.

Table 1.
Missing values in crisis sample.
This table lists the missing and total number of observation in the sample from 2007.01.01-2009.12.31, defined as the period of crisis.

| VARIABLES | Missing | Total | Percent Missing |
|---|---|---|---|
| CAT | 0 | 155 | 0.00 % |
| SPX | 0 | 155 | 0.00 % |
| CorpBond | 9 | 155 | 5.81 % |

Table 2.
Missing values in post-crisis sample.
This table lists the missing and total number of observation in the sample from 2010.01.01-2017.03.31, defined as the post-crisis period.

| VARIABLES | Missing | Total | Percent Missing |
|---|---|---|---|
| CAT | 0 | 379 | 0.00 % |
| SPX | 0 | 379 | 0.00 % |
| CorpBond | 21 | 379 | 5.54 % |

Swiss Re has constructed several indices based on five different portfolios: Global, Global Unhedged, USD Cat Bonds, BB Cat Bonds and US Wind Cat Bonds. Since there is no public exchange market for Cat bonds, the indices are estimated using indicative secondary market information. Previous researchers, e.g. Cummin & Weiss, have used Swiss Re indices as a benchmark for the Cat bond market. For this study, the Swiss Re Global Cat Bond Total Return Index (Bloomberg ticker: SRGLTRR) is used as a proxy for the global Cat bond market. The index tracks the performance of all Cat bonds, denominated in all currencies, issued under Rule 144A. The index is not subject to forex risk due to currency hedging and all the bonds of the index that are non-USD denominated bonds are converted into USD at the bond's settlement day. (Swiss Re, 2014) This index is chosen to capture a globally diversified portfolio of Cat bonds while avoiding the influence of foreign exchange risk.

As a proxy for the equity market, the S&P 500 is used, which is a total return index of the 500 biggest listed companies in the U.S. The S&P 500 is chosen because the biggest part of the Cat bond issues is denominated in U.S. dollars (Kish, 2016) and it is also assumed to be a useful index in a global perspective considering the multinational reach of the companies within it.

The corporate bond market is represented by the BofA Merrill Lynch US High Yield BB Effective Yield Index. This is an effective yield index, which takes compounding effect into account by re-investing interest payments, and is therefore comparable to the other total return indices used. The index tracks the performance of USD denominated below investment grade corporate bonds (equivalent to BB or lower), rated by Moody's, S&P and Fitch. Cat bonds are usually rated BB, B or CCC (Kish, 2016) which is why an index of high yielding bonds is suitable. Analogously with the S&P 500, we find a USD denominated corporate bond index appropriate because the majority of the Cat bonds are issued in the U.S.

## 3.2 Control variables

We use time series (TS) regressions to test the correlation between Cat bonds and the two other asset classes: stocks and bonds. Control variables are included to account for possible endogeneity problems.

### 3.2.1 Time and seasonal trends

We usually do not expect there to be a time trend when observing returns, but previous research of Cummins & Weiss (2009) has shown that Cat bond returns have decreased over time and therefore we suspect a negative time trend in the data. When testing each period individually the models are not significant, therefore, we test for a time trend in the total period of 2007 to early 2017 to detect possible time trends.

We test the hypothesis:

$$CAT = \propto_0 + \propto_1 t + U_t$$

$$H_0 : \propto_1 = 0$$

$$H_A : \propto_1 \neq 0$$

The results in table 3 allow us to reject the null and show a significant and slightly negative time trend. To adjust for this time trend we include a time variable in the regression model even though the coefficient in the regression is very low.

Table 3.
Time trend.
This table presents the test of a time trend in the total period of 2007.01.01-2017.03.31. Where CAT is the weekly return in the Swiss Re Global Cat Bond TR Index and t is a weekly time variable.

| VARIABLES | CAT |
|---|---|
| | |
| t | -1.90e-04** |
| | (8.25e-05) |
| Constant | 0.203*** |
| | (0.029) |
| | |
| Observations | 534 |
| R-squared | 0.009 |
| Prob > F | 0.022** |
| *** p<0.01, ** p<0.05, * p<0.1 | |

There might also be seasonal trends in Cat bond returns. According to ARTEMIS, a news, analysis and data portal of alternative investments, there is a seasonal price change in Cat bonds due to weather patterns such as windstorm- and hurricane seasons (ARTEMIS, 2012). This pattern could also be reflected in Cat bond returns. Similar to the time trend regression, we use the total time period in order to get enough observations.

We test the hypothesis:

$$CAT = ß_0 + ß_1 Q1_t + ß_2 Q2_t + ß_3 Q3_t + U_t$$
$$H_0: ß_1 = ß_2 = ß_3 = 0$$
$$H_A: At\ least\ one\ of\ ß_1, ß_2\ and\ ß_3 \neq 0$$

Where Q1, Q2 and Q3 are quarterly dummies that take the value 1 if the observation is in the quarter represented and 0 otherwise. The fourth quarter (Q4) is the reference. We conduct an F-test of joint significance and get a p-value of 0.000. This allows us to reject the null at a 1% level and we conclude that there is a significant seasonal trend. To account for this pattern, we include seasonal dummies Q1, Q2 and Q3 as control variables in the regression of Cat bond returns.

### 3.2.2 Risk-free interest rate

The interest rates of Cat bonds are based on the risk-free rate, usually on the three-month Treasury bill, LIBOR or EURIBOR rate (Kish, 2016). The risk-free rate also affects the return of corporate bonds and equity, since investors are assumed to be risk averse and demand a risk premium above the risk-free rate when investing in risky assets (Reilly & Brown, 2012, p. 182). Hence, we find it suitable to control for the risk-free rate in the regression and the BofA Merrill Lynch 3-Month U.S. Treasury Bill Index is used to proxy the 3-month U.S. Treasury Bill rate.

### 3.2.3 Risk aversion

Portfolio theory predicts that investors are risk averse, and the expectation is that there is a positive relationship between risk and return. (Reilly & Brown, 2012, p. 182). Changes in attitude towards risk are therefore assumed to affect both returns in the Cat bond-, the stock- and the corporate bond market, giving rise to a possible endogeneity problem. To adjust for this, we include a control variable for risk aversion in the model. There are several indices to measure attitudes towards risk in the market. These indices are commonly based on portfolio theory where the level of risk aversion is estimated by looking at the excess return demanded by investors when taking on additional risk.

In the empirical analysis we use BofA Merrill Lynch Global Financial Stress Index with focus on risk appetite (Bloomberg ticker: GFSIRISK) as a proxy for the level of risk aversion. This index is used because it is presented on a daily basis and uses data across different markets: global credit, equity, interest rates, forex and commodity. The index contains both transactions on public exchanges as well as OTC-transactions. (Reuters, 2010) Our expectation is that the level of risk aversion is higher during periods following financial distress and by observing the index fluctuations visually in graph 1 we see that it follows our expected pattern.

**Graph 1.**

BofA ML GFSI Risk Index 2007.01.01-2017.03.31.

## 3.3 Serial correlation and heteroscedasticity

To see that the estimates are unbiased and that the standard errors are correct we test the properties for TS regression in a large sample. First, we test for serial correlation in the dependent variable in both periods separately by observing the correlation between $\mathrm{CAT_t}$ and $\mathrm{CAT_{t-1}}$. We find that the variable is weakly dependent (ρ = 0.17).

Then we test for serial correlation in the error term by predicting the error term U and testing the hypothesis:

$$\widehat{U}_t = \rho\widehat{U}_{t-1} + \varepsilon_t$$
$$H_0: \rho = 0$$
$$H_A: \rho \neq 0$$

We run the regression and find no significant evidence for serial correlated errors in either of the samples.

Testing for heteroscedasticity in each period separately we get no significance in the models (F-value>0.05), therefore we test for this in the total period of 2007.01.01-2017.03.31. We test the hypothesis:

$$\widehat{U}_t^2 = \vartheta_0 + \vartheta_1 CAT_{t-1} + \varepsilon_t$$
$$H_0: \vartheta_1 = 0$$
$$H_A: \vartheta_1 \neq 0$$

By running this regression, we find significant evidence for heteroscedasticity, which is adjusted for by using robust standard errors in the regression. We also check for heteroscedasticity in the variance to see if we can predict current volatility by looking at volatility in the past by testing the hypothesis:

$$\widehat{U}_t^2 = \tau_0 + \tau_1\widehat{U}_{t-1}^2 + \tau_2 CAT_{t-1} + \varepsilon_t$$
$$H_0: \tau_1 = 0$$
$$H_A: \tau_1 \neq 0$$

We find no evidence of heteroscedasticity in the error term. When using robust standard errors, we therefore conclude that all properties of the OLS estimator in time series regression hold.

## 3.4 Models

### 3.4.1 Correlation

To test the correlation hypotheses we conduct TS regressions. The statistical software Stata is used to run the TS regressions. The models are as following:

$$CAT = \varphi_0 + \varphi_1 SPX_t + \varphi_2 RiskFree_t + \varphi_3 RiskAversion_t + \varphi_4 t + \varphi_5 Q1_t + \varphi_6 Q2_t + \varphi_7 Q3_t + U_t$$
$$CAT = \gamma_0 + \gamma_1 CorpBond_t + \gamma_2 RiskFree_t + \gamma_3 RiskAversion_t + \gamma_4 t + \gamma_5 Q1_t + \gamma_6 Q2_t + \gamma_7 Q3_t + U_t$$

Where CAT, SPX, CorpBond and RiskFree are the weekly return in the Swiss Re Global Cat Bond Total Return Index, the S&P 500, the BofA Merrill Lynch US High Yield BB Effective Yield Index and the BofA Merrill Lynch 3-Month U.S. Treasury Bill Index, respectively. The return is calculated as:

$$R_{i,t} = \frac{P_{i,t}}{P_{i,t-1}} - 1$$ *Where $P_{i,t}$ is the price of index i in week t*

The variable RiskAversion is the BofA Merrill Lynch Global Financial Stress Index. The variable t is the time variable and Q1, Q2 and Q3 are the quarterly dummies, all included as control variables for time- and seasonal trends.

In the first model, CAT is the dependent variable and SPX is the variable of interest. In the second model, CAT is the dependent variable and CorpBond is the variable of interest. We run the models and add one control variable at a time.

These models are used to test the following hypotheses:

$H_1$: $\varphi_1 = 0$
$H_{A,1}$: $\varphi_1 \neq 0$

$H_2$: $\gamma_1 = 0$
$H_{A,2}$: $\gamma_1 \neq 0$

### 3.4.2 Risk-adjusted return

We use Sharpe ratios to compare the risk-adjusted return across different asset classes. Sharpe ratio is an industry standard to measure the *"risk premium return earned per extra unit of total risk"* (Reilly & Brown, 2012, p. 965). In Andrew Lo's article *"The Statistics of Sharpe Ratios"* from 2002, he suggests two methods to calculate Sharpe ratio estimators and their statistical properties. In the first method returns are assumed to be independently and identically distributed (IID). In the second, more general method, this assumption is not made. The non-IID method incorporates phenomena such as autocorrelation and heteroscedasticity, which are regularly observed in financial time series. However, the non-IID method requires mathematics and statistics too advanced for this thesis. Therefore, we use Lo's first method and assume that returns are IID to derive the distribution and the test statistic of the Sharpe ratio estimator. The second assumption we make is that there is no covariance between the returns of the different indices and therefore no covariance between the Sharpe ratio estimators. These assumptions and their potential weaknesses are further discussed in the robustness section of the thesis.

The Sharpe ratio (SR) is defined as following:

$$SR = \frac{\mu - R_f}{\sigma}$$

Where

$\mu \equiv E[R_t]$ $\sigma^2 \equiv Var(R_t)$ $\sigma = \sqrt{\sigma^2}$ $R_f$ *is the risk-free rate*

To estimate the population parameters μ and σ we use the sample of historical returns ($R_1$, $R_2$, … , $R_T$) and compute the estimators:

$$\hat{\mu} = \frac{1}{T}\sum_{t=1}^{T} R_t \qquad \hat{\sigma} = \sqrt{\frac{1}{T}\sum_{t=1}^{T}(R_t - \hat{\mu})^2}$$

We use $\hat{\mu}$ and $\hat{\sigma}$ to compute the Sharpe ratio estimator:

$$\widehat{SR} = \frac{\hat{\mu} - R_f}{\hat{\sigma}}$$

Using a large sample, due to the central limit theorem, the Sharpe ratio can be approximated by:

$$\widehat{SR} \sim N(SR, Var(\widehat{SR}))$$

Under the assumption that returns are IID, Lo (2002) shows that:

$$Var(\widehat{SR}) = \frac{1 + \frac{1}{2}SR^2}{n}$$

Where *n* is the number of observations

The difference of two sample means of normally distributed variables with no covariance has the following variance:

$$Var(\widehat{SR}_x - \widehat{SR}_y) = Var(\widehat{SR}_x) + Var(\widehat{SR}_y) \qquad \text{which gives:}$$

$$Var(\widehat{SR}_x - \widehat{SR}_y) = \frac{1 + \frac{1}{2}SR_x{}^2}{n_x} + \frac{1 + \frac{1}{2}SR_y{}^2}{n_y}$$

The estimated variance and standard error of the Sharpe ratio estimator is then:

$$\widehat{Var}(\widehat{SR}_x - \widehat{SR}_y) = \frac{1 + \frac{1}{2}\widehat{SR}_x^2}{n_x} + \frac{1 + \frac{1}{2}\widehat{SR}_y^2}{n_y}$$

$$\widehat{SE}(\widehat{SR}_x - \widehat{SR}_y) = \sqrt{\frac{1 + \frac{1}{2}\widehat{SR}_x^2}{n_x} + \frac{1 + \frac{1}{2}\widehat{SR}_y^2}{n_y}}$$

The test statistic for $SR_x - SR_y$ when $Var(SR_x)$ and $Var(SR_x)$ are unknown and cannot be assumed equal is given by:

$$t_{df} = \frac{(\widehat{SR}_x - \widehat{SR}_y) - d_0}{\sqrt{\frac{1+\frac{1}{2}\widehat{SR}_x^2}{n_x} + \frac{1+\frac{1}{2}\widehat{SR}_y^2}{n_y}}} \qquad df = \frac{\left((1+\frac{1}{2}\widehat{SR}_x^2)/n_x + (1+\frac{1}{2}\widehat{SR}_y^2)/n_y\right)^2}{\left((1+\frac{1}{2}\widehat{SR}_x^2)/n_x\right)^2 \big/ (n_x-1) + \left((1+\frac{1}{2}\widehat{SR}_y^2)/n_y\right)^2 \big/ (n_y-1)}$$

We use excel to manually compute the t-statistic and test the following hypotheses:

$H_3: SR_{CAT} - SR_{SPX} \leq 0$
$H_{A,3}: SR_{CAT} - SR_{SPX} > 0$

$H_4: SR_{CAT} - SR_{CorpBond} \leq 0$
$H_{A,4}: SR_{CAT} - SR_{CorpBond} > 0$

## 3.5 Descriptive statistics

This section displays descriptive statistics of the dependent and independent variables. Since these summary statistic means are arithmetic, i.e. do not take compounding effects into account, they do not allow us to draw conclusions about the compounded returns of the three markets but they give an indication of the variables' movement in the two periods.

Table 4.

Descriptive statistics of the dependent variable, variables of interest and control variables of the crisis sample 2007.01.01-2009.12.31, where CAT is the weekly return of the Swiss Re Global Cat Bond TR Index, SPX is the weekly return of the S&P 500, CorpBond is the weekly return of the BofA ML High Yield Corporate Bond Index, RiskFree is the 3-month risk-free rate proxy and RiskAversion is the proxy for risk aversion based on the BofA ML GFSI.

| VARIABLES | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|
| CAT | 0.187 | 0.355 | -2.440 | 1.339 |
| SPX | -0.079 | 3.602 | -18.195 | 12.026 |
| CorpBond | 0.075 | 1.839 | -10.862 | 5.499 |
| RiskFree | 0.047 | 0.052 | -0.070 | 0.252 |
| RiskAversion | 0.679 | 1.005 | -0.670 | 3.300 |

Table 5.

Descriptive statistics of the dependent variable, variables of interest and control variables of the post-crisis sample 2010.01.01-2017.03.31, where CAT is the weekly return of the Swiss Re Global Cat Bond TR Index, SPX is the weekly return of the S&P 500, CorpBond is the weekly return of the BofA ML High Yield Corporate Bond Index, RiskFree is the 3-month risk-free rate proxy and RiskAversion is the proxy for risk aversion based on the BofA ML GFSI.

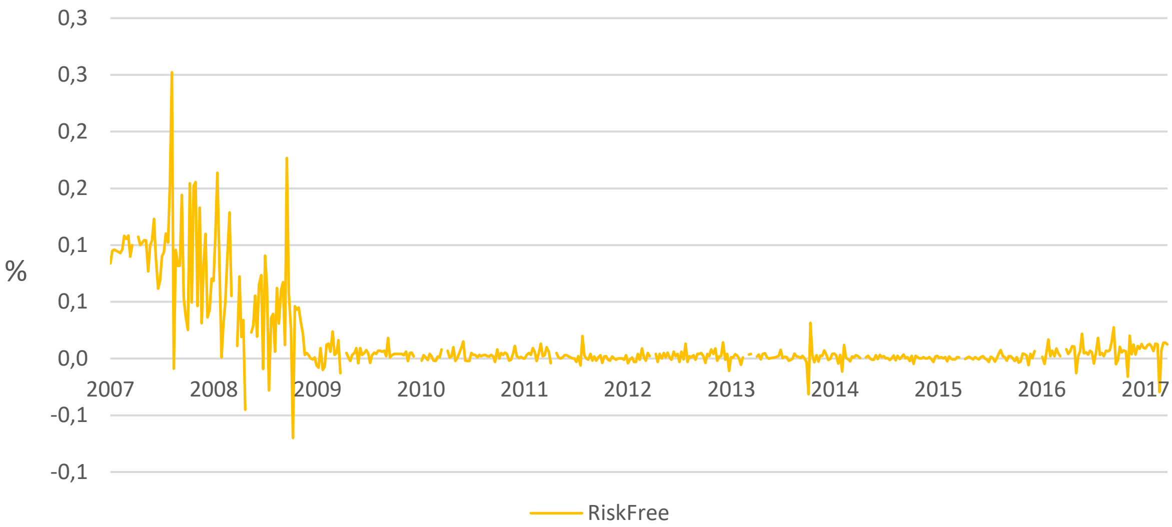
| VARIABLES | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|
| CAT | 0.137 | 0.299 | -2.463 | 1.735 |
| SPX | 0.215 | 1.972 | -7.189 | 7.389 |
| CorpBond | 0.145 | 0.754 | -2.833 | 3.088 |
| RiskFree | 0.002 | 0.006 | -0.031 | 0.031 |
| RiskAversion | 0.149 | 0.371 | -0.550 | 1.370 |

As we see in table 4, Cat bonds had the highest average return during the crisis period and a lower standard deviation in this period than both equity and corporate bonds. In the post-crisis period, shown in table 5, the equity- and corporate bond indices each have an average return that is higher than that of the Cat bond index, but Cat bond returns still show the lowest volatility of the three.

The return of the risk-free rate shows higher volatility during the crisis period than during the post-crisis period and has a much lower average return after the crisis. This is visualized in graph 2. In graph 3 we see that equity- and corporate bond returns show noticeable volatility over the entire period. The volatility of the risk aversion index can be seen in graph 1.

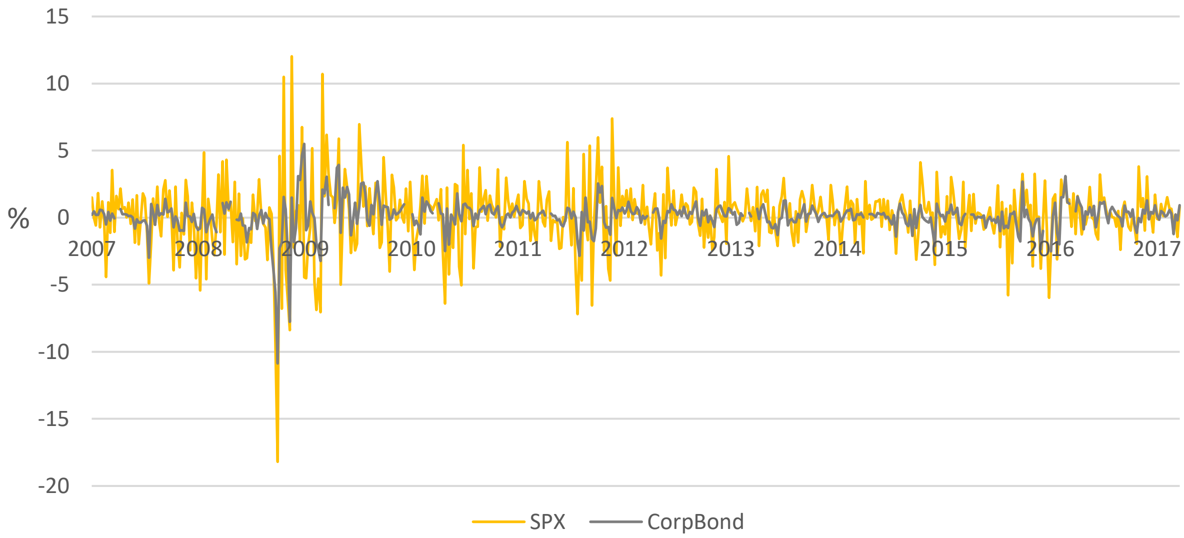
Graph 2.

Weekly return of the BofA ML 3-Month U.S. Treasury Bill Index, 2007.01.01-2017.03.31.




Graph 3.

Weekly return of the S&P 500 and the BofA ML US High Yield BB Effective Yield Index, 2007.01.01-2017.03.31.



# 4. Results

## 4.1 Correlation during the crisis

The results found from testing the correlation hypotheses in the crisis period are presented in table 6 and table 7. The results in table 6 allow us to reject $H_1$ at a 10 % significance level when including all control variables. This means we can show a positive correlation between Cat bond and equity returns with a coefficient of 0.030. The results also show significance in the RiskAversion variable and some explanatory power of a positive time trend. Comparing column (2) with column (3) to (5) we find that when adjusting for risk aversion, the explanatory power of SPX on CAT decreases.

**Table 6.**

Regression Cat bond- and equity market returns, 2007.01.01-2009.12.31.

This table presents the test of $H_1$ in the crisis period. CAT is the weekly return in the Swiss Re Global Cat Bond TR Index, SPX is the weekly return in the S&P 500, RiskFree is the 3-month risk-free rate proxy and RiskAversion is the proxy for risk aversion based on the BofA ML GFSI. The variable t is a weekly time variable and Q1, Q2 and Q3 are quarterly dummies.

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| VARIABLES | CAT | CAT | CAT | CAT | CAT |
| | | | | | |
| SPX | 0.030 | 0.035* | 0.030* | 0.030* | 0.030* |
| | (0.020) | (0.020) | (0.018) | (0.017) | (0.017) |
| RiskFree | | 1.233** | 0.279 | 1.412 | 1.332 |
| | | (0.580) | (0.664) | (0.897) | (0.945) |
| RiskAversion | | | -0.084** | -0.116*** | -0.126** |
| | | | (0.039) | (0.044) | (0.051) |
| t | | | | 0.002** | 0.003** |
| | | | | (0.001) | (0.001) |
| Q1 | | | | | 0.090 |
| | | | | | (0.075) |
| Q2 | | | | | -0.036 |
| | | | | | (0.053) |
| Q3 | | | | | 0.047 |
| | | | | | (0.089) |
| Constant | 0.189*** | 0.139*** | 0.241*** | 0.025 | -0.009 |
| | (0.027) | (0.045) | (0.052) | (0.116) | (0.147) |
| | | | | | |
| Observations | 155 | 146 | 146 | 146 | 146 |
| R-squared | 0.095 | 0.134 | 0.170 | 0.204 | 0.220 |
| Prob > F | | | | | 0.020** |
| Robust standard errors in parentheses | | | | | |
| *** p<0.01, ** p<0.05, * p<0.1 | | | | | |

Table 7.
Regression Cat bond- and corporate bond market returns, 2007.01.01-2009.12.31.
This table presents the test of $H_2$ in the crisis period. CAT is the weekly return in the Swiss Re Global Cat Bond TR Index, CorpBond is the weekly return in the BofA ML High Yield Corporate Bond Index, RiskFree is the 3-month risk-free rate proxy and RiskAversion is the proxy for risk aversion based on the BofA ML GFSI. The variable t is a weekly time variable and Q1, Q2 and Q3 are quarterly dummies.

| | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|
| VARIABLES | CAT | CAT | CAT | CAT | CAT |
| | | | | | |
| CorpBond | 0.088** | 0.096** | 0.087** | 0.084** | 0.085** |
| | (0.042) | (0.041) | (0.038) | (0.038) | (0.037) |
| RiskFree | | 1.480** | 0.749 | 1.508 | 1.328 |
| | | (0.601) | (0.747) | (0.972) | (0.995) |
| RiskAversion | | | -0.063* | -0.088*** | -0.095** |
| | | | (0.034) | (0.034) | (0.039) |
| t | | | | 0.002* | 0.002 |
| | | | | (0.001) | (0.001) |
| Q1 | | | | | 0.007 |
| | | | | | (0.054) |
| Q2 | | | | | -0.098* |
| | | | | | (0.055) |
| Q3 | | | | | 0.023 |
| | | | | | (0.090) |
| Constant | 0.185*** | 0.115** | 0.194*** | 0.044 | 0.082 |
| | (0.029) | (0.047) | (0.057) | (0.115) | (0.132) |
| | | | | | |
| Observations | 146 | 146 | 146 | 146 | 146 |
| R-squared | 0.197 | 0.240 | 0.260 | 0.277 | 0.292 |
| Prob > F | | | | | 0.016** |
| Robust standard errors in parentheses | | | | | |
| *** p<0.01, ** p<0.05, * p<0.1 | | | | | |

The results in table 7 are stronger than the results in the previous regression and allow us to reject $H_2$ that Cat bond returns are not correlated with returns at the corporate bond market at a 5% significance level. The variable of interest CorpBond has an explanatory power of the dependent variable CAT and that the correlation is positive with a coefficient of 0.085. Comparing the results in column (7) with column (8) to (10) we find that the explanatory power of corporate bond market returns on Cat bond returns decrease when controlling for risk aversion. We also find that there is no longer significance in the controlling variable RiskFree when also controlling for risk aversion. This is the case when testing both $H_1$ and $H_2$.

## 4.2 Correlation after the crisis

Table 8 presents the results found from testing $H_1$ that Cat bond returns are not correlated with equity returns, in the post-crisis period. As we see in the table there is no significance in the SPX variable and therefore we cannot reject the null hypothesis. These results from the post-crisis period support the claim that there is no proof of a significant correlation between the Cat bond- and the equity market.

**Table 8.**

Regression Cat bond- and equity market returns, 2010.01.01-2017.03.31.

This table presents the test of $H_1$ in the post-crisis period. CAT is the weekly return in the Swiss Re Global Cat Bond TR Index, SPX is the weekly return in the S&P 500, RiskFree is the 3-month risk-free rate proxy and RiskAversion is the proxy for risk aversion based on the BofA ML GFSI. The variable t is a weekly time variable and Q1, Q2 and Q3 are quarterly dummies.

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| VARIABLES | CAT | CAT | CAT | CAT | CAT |
| | | | | | |
| SPX | -0.007 | -0.007 | -0.007 | -0.007 | -0.006 |
| | (0.009) | (0.009) | (0.009) | (0.009) | (0.010) |
| RiskFree | | -1.148 | -1.148 | -0.444 | -0.335 |
| | | (2.331) | (2.378) | (2.543) | (2.606) |
| RiskAversion | | | -1.86e-05 | -0.024 | -0.031 |
| | | | (0.043) | (0.047) | (0.048) |
| t | | | | -2.18e-04 | -2.29e-04 |
| | | | | (0.000) | (0.000) |
| Q1 | | | | | -0.015 |
| | | | | | (0.053) |
| Q2 | | | | | -0.014 |
| | | | | | (0.051) |
| Q3 | | | | | 0.153*** |
| | | | | | (0.054) |
| Constant | 0.139*** | 0.142*** | 0.142*** | 0.191*** | 0.161*** |
| | (0.015) | (0.015) | (0.015) | (0.044) | (0.061) |
| | | | | | |
| Observations | 379 | 358 | 358 | 358 | 358 |
| R-squared | 0.002 | 0.002 | 0.002 | 0.007 | 0.062 |
| Prob > F | | | | | 0.000*** |
| Robust standard errors in parentheses | | | | | |
| *** p<0.01, ** p<0.05, * p<0.1 | | | | | |

The results in table 9 are those from testing the correlation between Cat bond returns and returns in the corporate bond market ($H_2$). Similar to the results we get for the equity market, there is no significance in the CorpBond variable in any of the three significance levels. Therefore, we cannot reject the null and prove a correlation between returns in the Cat bond market and the corporate bond market in the post-crisis period. We find no predictive power of the risk-free rate on Cat bond returns in neither of the result tables for the post-crisis period.

**Table 9.**

Regression Cat bond- and corporate bond market returns, 2010.01.01-2017.03.31.

This table presents the test of $H_2$ in the post-crisis period. CAT is the weekly return in the Swiss Re Global Cat Bond TR Index, CorpBond is the weekly return in the BofA ML High Yield Corporate Bond Index, RiskFree is the 3-month risk-free rate proxy and RiskAversion is the proxy for risk aversion based on the BofA ML GFSI. The variable t is a weekly time variable and Q1, Q2 and Q3 are quarterly dummies.

| | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|
| VARIABLES | CAT | CAT | CAT | CAT | CAT |
| | | | | | |
| CorpBond | 0.015 | 0.015 | 0.015 | 0.013 | 0.019 |
| | (0.017) | (0.017) | (0.017) | (0.017) | (0.017) |
| RiskFree | | -0.899 | -0.911 | -0.226 | -0.146 |
| | | (2.355) | (2.410) | (2.562) | (2.632) |
| RiskAversion | | | 0.003 | -0.020 | -0.027 |
| | | | (0.042) | (0.046) | (0.047) |
| t | | | | -2.13e-04 | -2.21e-04 |
| | | | | (0.000) | (0.000) |
| Q1 | | | | | -0.017 |
| | | | | | (0.054) |
| Q2 | | | | | -0.009 |
| | | | | | (0.050) |
| Q3 | | | | | 0.156*** |
| | | | | | (0.053) |
| Constant | 0.135*** | 0.137*** | 0.137*** | 0.185*** | 0.153** |
| | (0.016) | (0.016) | (0.015) | (0.045) | (0.061) |
| | | | | | |
| Observations | 358 | 358 | 358 | 358 | 358 |
| R-squared | 0.001 | 0.002 | 0.002 | 0.006 | 0.063 |
| Prob > F | | | | | 0.000*** |
| Robust standard errors in parentheses | | | | | |
| *** p<0.01, ** p<0.05, * p<0.1 | | | | | |

## 4.3 Risk-adjusted return

Sharpe ratios are often annualized when presented, as we do in table 10. This is done to get reference points of the three indices. However, one should be vigilant when annualizing Sharpe ratios by multiplying with the square root of number of periods in a year, since this can lead to erroneous estimates (Lo, 2002). This is why weekly values are used in the subsequent analysis.

As shown in table 10, the annualized risk-adjusted return has been higher for Cat bonds than for equity and corporate bonds. This is true for all three periods.

Tables 11-13 show the results from conducting difference of means t-test of the Sharpe ratios to determine whether risk-adjusted return has been significantly higher in the Cat bond market than the markets for the two other asset classes. For the crisis period we get a difference of means in weekly risk-adjusted return between CAT and SPX of 0.48 and between CAT and CorpBond of 0.41. The differences are significant at a 1% level. We reject the null hypotheses $H_3$ and $H_4$ in the crisis period and conclude that the risk-adjusted return in the Cat bond market has been higher than those of the equity- and corporate bond markets.

**Table 10.**
Annualized Sharpe ratio per market.
This table presents the annualized[1] Sharpe ratios for the crisis period 2007.01.01-2009.12.31, post-crisis period 2010.01.01-2017.03.31 and over the total period (crisis and post-crisis). CAT, SPX and CorpBond are the Sharpe ratios based on weekly returns of the Swiss Re Global Cat Bond TR Index, the S&P 500 and the BofA ML High Yield Corporate Bond Index, respectively.

| VARIABLES | CAT | SPX | CorpBond |
|---|---|---|---|
| Crisis | 2.875 | -0.400 | 0.110 |
| Post-crisis | 3.183 | 0.739 | 1.361 |
| Total period | 3.064 | 0.236 | 0.670 |

[1] The Sharpe ratios have been annualized using weekly Sharpe Ratios $\times \sqrt{52}$

**Table 11.**
Sharpe ratios difference of means, t-test, 2007.01.01-2009.12.31.
This table presents the difference of means t-test of Sharpe ratios for the crisis period. $\hat{\mu}$ is the sample mean of weekly returns and $\hat{\sigma}$ is the standard deviation of weekly returns of the Swiss Re Global Cat Bond TR Index, the S&P 500 and the BofA ML High Yield Corporate Bond Index. RiskFree is the 3-month risk-free rate proxy, $\widehat{\text{Var}}(\widehat{\text{SR}})$ is the variance of the Sharpe ratio sample mean and $\widehat{\text{SE}}(\widehat{\text{SR}})$ is the standard error of the Sharpe ratio sample mean. The variables diff CAT SPX and diff CAT CorpBond are the difference of means.

| | | | | | | |
|---|---|---|---|---|---|---|
| VARIABLES | CAT | SPX | CorpBond | RiskFree | diff CAT SPX | diff CAT CorpBond |
| # of observations | 146 | 146 | 146 | 146 | 146 | 146 |
| $\hat{\mu}$ return % | 0.191 | -0.157 | 0.075 | 0.047 | | |
| $\hat{\sigma}$ return % | 0.362 | 3.665 | 1.833 | | | |
| Sharpe ratio | 0.399 | -0.055 | 0.015 | | 0.480*** | 0.410*** |
| $\widehat{\text{Var}}(\widehat{\text{SR}})$ | 0.007 | 0.007 | 0.007 | | 0.009 | 0.009 |
| $\widehat{\text{SE}}(\widehat{\text{SR}})$ | | | | | 0.095 | 0.095 |
| t-statistic | | | | | 5.057 | 4.315 |
| df | | | | | 290 | 290 |
| *** p<0.01, ** p<0.05, * p<0.1 | | | | | | |

Table 12.

Sharpe ratios difference of means, t-test, 2010.01.01-2017.03.31.

This table presents the difference of means t-test of Sharpe ratios for the post-crisis period. $\hat{\mu}$ is the sample mean of weekly returns and $\hat{\sigma}$ is the standard deviation of weekly returns of the Swiss Re Global Cat Bond TR Index, the S&P 500 and the BofA ML High Yield Corporate Bond Index. RiskFree is the 3-month risk-free rate proxy, $\widehat{\text{Var}}(\widehat{\text{SR}})$ is the variance of the Sharpe ratio sample mean and $\widehat{\text{SE}}(\widehat{\text{SR}})$ is the standard error of the Sharpe ratio sample mean. The variables diff CAT SPX and diff CAT CorpBond are the difference of means.

| | | | | | | |
|---|---|---|---|---|---|---|
| VARIABLES | CAT | SPX | CorpBond | RiskFree | diff CAT SPX | diff CAT CorpBond |
| # of observations | 358 | 358 | 358 | 358 | 358 | 358 |
| $\hat{\mu}$ return % | 0.137 | 0.204 | 0.145 | 0.002 | | |
| $\hat{\sigma}$ return % | 0.306 | 1.969 | 0.753 | | | |
| Sharpe ratio | 0.441 | 0.102 | 0.189 | | 0.322*** | 0.236*** |
| $\widehat{\text{Var}}(\widehat{\text{SR}})$ | 0.003 | 0.003 | 0.003 | | 0.005 | 0.005 |
| $\widehat{\text{SE}}(\widehat{\text{SR}})$ | | | | | 0.071 | 0.071 |
| t-statistic | | | | | 4.573 | 3.337 |
| df | | | | | 713 | 713 |
| *** p<0.01, ** p<0.05, * p<0.1 | | | | | | |

Table 12 shows the results found from testing the risk-adjusted return hypotheses in the post-crisis period. The difference of means in weekly risk-adjusted return between the Cat bond market and the equity market is 0.322. For the Cat bond and the corporate bond market the difference is somewhat lower, at 0.236. Similar to the crisis period, the results are significant at a 1% level and allow us to reject $H_3$ and $H_4$. Thus, risk-adjusted return in the Cat bond market has been higher than those of the equity- and corporate bond market in the post-crisis period.

Lastly, we present the results found from testing the entire period from January 2007 until March 2017 in table 13. We find that the difference in risk-adjusted return in the Cat bond market compared to the stock market is 0.322 whereas the difference between the Cat bond- and the corporate bond market is 0.236. The results show significantly higher risk-adjusted return in the Cat bond market at a 1% level and allow us to reject both $H_3$ and $H_4$. For the entire period we conclude that risk-adjusted return has been higher in the Cat bond market compared to the markets of the two other asset classes.

Table 13.
Sharpe ratios difference of means, t-test, 2007.01.01-2017-03-31.
This table presents the difference of means t-test of Sharpe ratios for the total period. $\hat{\mu}$ is the sample mean of weekly returns and $\hat{\sigma}$ is the standard deviation of weekly returns of the Swiss Re Global Cat Bond TR Index, the S&P 500 and the BofA ML High Yield Corporate Bond Index. RiskFree is the 3-month risk-free rate proxy, $\widehat{Var}(\widehat{SR})$ is the variance of the Sharpe ratio sample mean and $\widehat{SE}(\widehat{SR})$ is the standard error of the Sharpe ratio sample mean. The variables diff CAT SPX and diff CAT CorpBond are the difference of means.

| | | | | | | |
|---|---|---|---|---|---|---|
| VARIABLES | CAT | SPX | CorpBond | RiskFree | diff CAT SPX | diff CAT CorpBond |
| # of observations | 504 | 504 | 504 | 504 | 504 | 504 |
| $\hat{\mu}$ return % | 0.153 | 0.100 | 0.124 | 0.015 | | |
| $\hat{\sigma}$ return % | 0.324 | 2.583 | 1.173 | | | |
| Sharpe ratio | 0.425 | 0.033 | 0.093 | | 0.392*** | 0.332*** |
| $\widehat{Var}(\widehat{SR})$ | 0.002 | 0.002 | 0.002 | | 0.004 | 0.004 |
| $\widehat{SE}(\widehat{SR})$ | | | | | 0.064 | 0.065 |
| t-statistic | | | | | 6.090 | 5.150 |
| df | | | | | 1004 | 1004 |
| *** p<0.01, ** p<0.05, * p<0.1 | | | | | | |

# 5. Analysis

In this section we analyze each time period separately and look at both correlation and risk-adjusted return results to discuss the value of Cat bonds for investors.

## 5.1 Crisis period 2007-2009

In line with previous research by Cummins & Weiss (2009) and Gürtler, Hibbeln & Winkelvos (2016) we find a significant correlation (beta) between returns in the Cat bond market and the equity- as well as the corporate bond market during the crisis period. Even so, the predictive power of returns in the equity- or corporate bond market on Cat bond returns is low. When we test the correlation with the equity market it generates a beta of approximately 0.03, and when testing against the corporate bond market the beta is approximately 0.09. The idea of Cat bonds as zero-beta assets is proven to be untrue during the crisis, but the low betas still suggest that Cat bonds have a very low systematic risk and therefore are beneficial for diversification.

Some of the Cat bonds outstanding during the crisis went into default when Lehman Brothers declared bankruptcy in 2008 and Gürtler, Hibbeln & Winkelvos (2016) have proven that the bankruptcy had an effect on Cat bond returns. Therefore, we suspect that some of the correlation is caused by the default of these bonds due to the swap counterparty and not due to the market decline. The restrictions implemented after this event described by Wattman & Fieg (2008) might in the case of future crises, generate even lower betas of Cat bonds.

When including a proxy for risk aversion in the model the results display lower betas. These findings suggest that some of the correlation with the equity- and corporate bond market can be explained by changes in attitudes towards risk during a period of crisis. Shown by the risk aversion index that we have used as a proxy in the models, investors' risk aversion increased during the crisis. Our expectation is that when the level of risk aversion increases, investors require a higher premium for taking on more risk in all parts of the capital market. This would affect returns on the equity-, corporate bond- and Cat bond markets negatively and the correlation between the different markets increases. These expectations are confirmed by the results and the findings allow us to statistically show what previously has been theoretically discussed by Bantwal & Kunreuther (2000) about the effect of risk aversion on Cat bond premiums.

The correlation between Cat bond- and corporate bond returns is higher than that of Cat bond- and equity returns. This result is not surprising and can be explained by the fact that Cat bonds and corporate bonds are both debt instruments, have similar ratings and the investors of the two instruments might have similar behavior. Cat bonds are initially issued to QIBs and are traded in large denominations, which are features we connect to the debt market rather than the equity market.

We would expect the risk-free rate to have relatively high and significant correlation with Cat bond returns in the model because Cat bonds are priced above a floating risk-free rate. This is supported by our findings before we include a proxy for risk aversion, which, when included, removes the significance of the risk-free rate proxy. A possible explanation for this is multicollinearity, since the variables for risk-free rate and risk aversion are negatively correlated during the crisis (table 14).

**Table 14.**
Correlation matrix, 3-month risk-free rate proxy and risk aversion proxy, 2007.01.01-2009-12-31.

| | RiskFree | RiskAversion |
|---|---|---|
| RiskFree | 1.00 | |
| RiskAversion | -0.54*** | 1.00 |
| *** p<0.01, ** p<0.05, * p<0.1 | | |

In addition to the low systematic risk, Cat bonds have outperformed both the equity- and corporate bond market, measured by risk-adjusted return during the crisis. The annualized Sharpe ratio for Cat bonds in the crisis period is 2.88 compared to -0.40 for equity and 0.11 for high yield corporate bonds and the weekly risk-adjusted returns are proven significantly higher for Cat bonds. This might be explained by the previous results concerning the correlation; the low beta gives a lower effect on Cat bond returns when the market fell during the crisis – the returns stay on a relatively high level and the volatility does not rise to the levels shown in the rest of the market. Our findings support the conclusion drawn by Kish (2016) that the risk incurred by investing in Cat bonds might to some extent be offset by the high returns.

Thus, for the crisis period we find low systematic risk and higher risk-adjusted returns in comparison to the other assets. Consequently, Cat bonds can be presented as valuable securities for diversification in a period of crisis and might be even more valuable in case of a future crisis because of the lessons learned and improvements made in the Cat bond market since the last one.

## 5.2 Post-crisis period 2010-2017

In the post-crisis period we do not get any significant results when testing the correlation hypotheses. This means that we cannot find any proof of correlation between Cat bond returns and neither stock- nor corporate bond returns. This is in agreement with previous results presented by Cummins & Weiss (2009) and Kish (2016) and supports our expectations that Cat bond returns are determined by the risk of natural disasters (i.e. their default risk) and not fluctuations in capital markets.

The expectation that Cat bonds are zero-beta assets is based on the idea of rational behavior of investors. On the contrary, Bantwal & Kunreuther (2000) suggest in their paper that investors are not completely rational when it comes to Cat bonds and that different biases affect the premiums, such as ambiguity aversion, loss aversion and risk aversion; even though the authors maintain the claim that Cat bonds are uncorrelated with the rest of the market. If risk aversion would be a determining factor in Cat bond premiums we would expect the coefficient to be negative and significant, but we find no explanatory power by the risk aversion proxy of Cat bond returns in the period after the crisis. The results therefore oppose the theoretical explanation made by Bantwal & Kunreuther (2000) that level of risk appetite in the market has an effect on investors' required premium for Cat bonds. The level of loss aversion should also be partly reflected in the risk aversion proxy because the index is calculated from both very risky assets and less risky assets. Other possible biases mentioned by Bantwal & Kunreuther (2000) such as ambiguity aversion due to investors' uncertainty about natural disasters are less likely to be captured by the risk aversion proxy and might still have an effect on premiums required.

As mentioned earlier, we expect the risk-free rate to be correlated with the Cat bond returns because of the pricing structure of Cat bonds. This is not in line with our findings for the post-crisis period and this can be explained by the low volatility in the risk-free rate after the crisis. The rationale of this explanation is that we find a correlation when the volatility is higher (during the crisis) but not when the volatility is low (post-crisis).

During the period from 2010 to the first quarter of 2017, the weekly average return of Cat bonds is lower than the return of both the equity- and corporate bond market. The mean return of Cat bonds is also lower than the return observed during the crisis. Generally, when a market grows and matures, it becomes more effective and the returns decline. As described by Wattman & Fieg (2008), the Cat bond market has become more standardized: the bonds are rated and the risks are now more isolated to the occurrence of natural disasters. These changes in combination with the performance during the crisis might be the reason for the increased attractiveness of Cat bonds, which we see in the continued growth of the market, and could explain why Cat bond returns are lower in the post-crisis period. Looking at the risk-adjusted returns however, we see that Cat bonds have outperformed both the stock market and the high yield corporate bond market. This is because of the low volatility of Cat bond returns relative to the volatility of stocks and corporate bonds. Again, this is the result of the low systematic risk that Cat bonds show after the crisis. The low volatility can also be connected to the reduced exogenous- and modelling risks due to standardization in the market.

The market after the crisis is known for very low interest rates, a phenomenon widely discussed by researchers. Cat bonds have a credit risk but because of their structure, with the floating interest rate as a base, the duration risk is low. According to Alloway (2016), this would suggest that investors in the low interest rate environment will turn away from Cat bonds and into other assets with longer maturity and thereby higher duration risks. This is the opposite of our findings when observing the Cat bond market in the low interest environment.

Similar to the crisis period, we find Cat bonds have been valuable assets to investors after the crisis, considering their low correlation with other markets. Even though the differences in Sharpe ratios are less pronounced during the post-crisis period, Cat bonds have clearly out-perform the stock market and the high yield segment of the corporate bond market.

### 5.3 Risk-adjusted return total period 2007-2017

We examine the total period to see how well Cat bonds have performed in different market environments. Observing the results, we find that Cat bonds' risk-adjusted return has been significantly higher than those of stocks and corporate bonds. The mean weekly return has been higher and the volatility has been lower in comparison to the other asset classes tested. These clear differences can be explained by the fact that Cat bonds were less affected by the crisis. This further strengthens the previous inferences that Cat bonds add value to an investor and that this is consistent in differing market conditions, even over a longer period of time.

## 6. Future research

The methods we have chosen to test the hypotheses is TS regressions and difference of means tests. An alternative approach to test if Cat bonds are a good instrument for diversification could be to synthesize two different portfolios with only one including Cat bonds and compare the two. This method calls for a more detailed dataset with information about individual Cat bonds that we do not have access to since Cat bonds are traded OTC. Using indices as proxies, we find the method chosen in this thesis more appropriate. If more detailed data would be obtained, the model could be developed even further.

Access to more detailed data about Cat bonds would also allow for future researchers to examine the different factors that impact Cat bond premiums. Kish (2016) provides input to the research by listing risks that might influence the required return and Bantwal & Kunreuther (2000) discuss biases that might affect the premiums. Both these papers have a theoretical rather than an empirical approach. An interesting empirical approach for future researchers could be to build a model that explains the effect of the different risks and biases on Cat bond premiums.

## 7. Robustness

### 7.1 Endogeneity and causality

The data we have of the Swiss Re Global Cat Bond TR Index does not contain information about the liquidity of the bonds traded within the index. This gives rise to a possible omitted variable problem, since investors demand higher premiums for illiquid assets. However, considering the size of the Cat bond market in comparison with the equity and corporate bond market, the liquidity of Cat bonds is unlikely to influence the returns in the other markets and we therefore believe that the estimates are unlikely to be biased because of this.

In the TS regression models we include a proxy for risk aversion based on an index to reduce possible endogeneity issues caused by the level of risk aversion in the market. There are two concerns about using this index as a proxy. First, in previous research, Bantwal & Kunreuther (2000) discuss the potential effect of other psychological factors such as ambiguity aversion, due to the lack of knowledge about Cat bonds and the uncertainty in modelling natural disaster, on Cat bond premiums. It is unlikely that the risk aversion proxy captures these imperfections, but since they do not directly alter the market returns of stocks and corporate bonds this should not give rise to an endogeneity problem. Second, the utility functions of investors are unobservable, which makes their risk aversion difficult to quantify and it is difficult to tell how well the index captures the true level of risk aversion. If the proxy cannot perfectly track the risk aversion, this still induces a possible endogeneity problem. A way of investigating this would be to extend the method with models involving different ways of measuring risk appetite.

Throughout this thesis we are interested in finding a correlation between the dependent variable and variables of interest and the method chosen does not allow us to make any conclusions about causality. Previous research by Wang & Kutan (2013) has shown that natural disasters do not have significant impact on the equity market. We do not test this hypothesis or include variables for natural disasters in the models and because of this we cannot make any statements about causal effects. It is not in our objective to draw conclusions about causality since our main interest is to examine the beta of Cat bonds.

In both the regression models for the post-crisis period, the R-squared is approximately 0.06. This is not considered as an issue since Cat bond returns mainly are determined by the probability of the bond being triggered (i.e. the probability of the disaster occurring) and other Cat bond characteristics such as modelling risks and initial costs of education.

## 7.2 Risk-free rate proxy

As a proxy for the risk-free rate we use the return of the BofA Merrill Lynch 3-Month U.S. Treasury Bill Index, which is based on the three-month U.S. treasury floating rate. For the period of the crisis, the results are in line with our expectation that the risk-free rate has an explanatory power on Cat bond returns. During this period there is sufficient volatility of the variable. For the period after the crisis the volatility of risk-free return is low and this is most likely the explanation to why the coefficient of the risk-free rate variable is not significant, which is in contrast to our expectations. To check the robustness of the risk-free rate proxy we test if the results differ when using the risk-free yield of a different index, US Generic Government 3-month yield (Bloomberg ticker: USGG3M), but get no significance in this case either. We also test if we find a correlation when using prices of the BofA Merrill Lynch 3-Month U.S. Treasury Bill Index instead of returns but the results are unchanged.

### 7.3 Sharpe ratio

One weakness in the Sharpe ratio computations is the simplifying assumption that returns are IID. It is highly likely that this assumption is violated by the financial time series we are studying due to autocorrelation and volatility clustering. Lo (2002) argues that ignoring these factors can lead to estimate errors. Still, this assumption is crucial in order for us to be able to test the significance of the results. Using our method, the differences in Sharpe ratios are very substantial, all significant at a 0.05% level, suggesting that the results would still hold even if the estimators to some degree are biased.

The other assumption we make is that the covariance between the Sharpe ratios is zero. Since we find little or no correlation (and consequently little or no covariance) in returns between Cat bonds and the other assets, the covariance of Sharpe ratios should not affect the results in a meaningful way. In addition, the significant betas we find are positive, meaning that the covariance is positive. This would increase the t-statistics, since the variance of the difference of means decreases with increased covariance.[1] Hence, we can safely make the assumption that there is no covariance between the Sharpe ratios.

The excess return of the S&P 500 (the return of the S&P 500 minus the risk-free return) during the crisis is negative, making the Sharpe ratio negative. Comparing positive and negative Sharpe ratios is somewhat problematic. Consider two different portfolios, A and B, with equal negative excess returns. If A has higher standard deviation, it will show a higher (less negative) Sharpe ratio and would seem like a more attractive investment. However, choosing between two portfolios with equal returns and different standard deviations, the best option is the portfolio with the lowest standard deviation, in this case B. In other words, the high volatility of the S&P 500 during the crisis increases the Sharpe ratio instead of lowering it. Since the results already allow us to reject the null at the 1% significance level, this has no effect on our findings.

[1] Since for dependent variables, $\mathrm{Var}(X - Y) = \mathrm{Var}(X) + \mathrm{Var}(Y) - 2\mathrm{Cov}(X, Y)$

# 8. Conclusion

Cat bonds offer vital protection to insurance companies by giving them access to reinsurance through the capital market. These instruments are often described as zero-beta assets in the literature. The rationale behind this is that the state of the economy has no influence on the likelihood of a natural disaster and that even large natural disasters have insignificant effect on the financial market. Our research demonstrates a significant correlation with the equity- as well as high yield corporate bond market during the subprime crisis. Thus, it allows us to disprove that Cat bonds are zero-beta instruments in such extreme market conditions. The results we present in this thesis indicate that this correlation between Cat bond returns and equity- and corporate bond returns partly can be explained by the investors' risk aversion during a financial crisis - a contribution to the behavioral aspect of Cat bond returns previously discussed by researchers but never statistically tested.

Nevertheless, supported by the low betas during the crisis, we suggest that Cat bonds still offer a relevant source of diversification. In addition to this we argue that improvements made in the Cat bond market after the subprime crisis might lower the correlation with the market in case of a similar event in the future. When further examining betas after the crisis we find no evidence of correlation between Cat bond returns and equity- or high yield corporate bond returns. This strengthens the argument that Cat bonds offer diversification to investors.

Moreover, when comparing the performance of the Cat bond market with the equity- and high yield corporate bond market by looking at weekly Sharpe ratios, thereby taking into account the systematic- as well as the idiosyncratic risk, we find that Cat bonds clearly have out-performed the two other asset classes. Cat bonds have a significantly higher risk-adjusted return during the crisis and post-crisis period. The high risk-adjusted returns of Cat bonds can be attributed to the low systematic risk of these instruments, which made them resilient to the market crash in 2007-2008. After the crisis the volatility of Cat bonds remains low, yielding a higher risk-adjusted return than those of stocks and high yield corporate bonds. Again, the low volatility can be explained by the low systematic risk and the structural improvements made in the Cat bond market.

Analyzing the correlation and risk-adjusted returns over the last 10 years we find some important insights of the continuously growing Cat bond market during and after a financial crisis. Not only do Cat bonds offer value to the insurance market, but as our research demonstrates, Cat bonds are low-beta instruments with high risk-adjusted return that also offer value to investors.

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