Catastrophe Bonds

An Evaluation Under Revised Collateral Structures

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May 20th, 2024

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Abstract

CAT bonds allow institutions to transfer insurance exposure from their balance sheet onto the capital market to hedge against catastrophe-linked payment obligations. For investors in the capital markets, CAT bonds are, at least theoretically, a means of employing capital to earn a return that is uncorrelated with alternative investments. Grounded in this theoretical approach, we investigates the potential for CAT bonds as a zero-beta investment class under the revised collateral structures implemented following the market's turmoil during the 2008 financial crisis, a period that prior scholars have used to disprove CAT bonds from a zero-beta perspective. We investigated a comprehensive seven-year period centred around the COVID-19 financial crisis by employing correlation and cointegration analysis. Our results indicate that CAT bonds exhibit zero-beta characteristics in the short run during both pre-crisis and crisis periods. However, the evidence is inconclusive for the post-crisis period. In the long run, our findings suggest that CAT bonds are zero-beta only when compared against alternative fixed-income investments. These empirical findings provide insights into previously unanswered queries and extend the knowledge framework on CAT bonds.

Keywords

Catastrophe bond, Zero-beta, Diversification.

Acknowledgements

I would like to express my sincere gratitude to the School of Economics and Management at Lund University for fostering academic excellence and offering continuous encouragement during my educational journey.

Thank you to Professor Hans Byström for extending your guidance and opinions throughout this research process.

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1 Introduction

1.1 Background

In late August 1992, Hurricane Andrew made landfall in the U.S. causing damages of $27 billion of which $15.5 billion was covered by insurance ($60 billion and $34 billion in 2024 dollars respectively). Andrew turned out to be an epiphany of the generally profound underestimation of risk associated with insurance against natural disasters as the hurricane ultimately forced eight insurance companies into insolvency. However, Andrew underscored the urgent necessity for advancements in the Insurance-Linked Securities (ILS) market, ultimately sowing the first seed of what would become the Catastrophe (CAT) bond market, with the first CAT bond being issued in 1997 (Insurance Information Institute, 2012).

A simple definition of CAT bonds follows from the Federal Reserve Bank of Chicago; "*A CAT bond is a security that pays the issuer when a predefined disaster risk is realised, such as a hurricane causing $500 million in insured losses or an earthquake reaching a magnitude of 7.0.*" (Polacek, 2018). Hence, at least theoretically, CAT bonds employ capital to earn returns in a market that is uncorrelated with the broader financial market, a fair assumption under the constraints that catastrophe risks are fairly small compared to the greater capital market. The zero-beta aspect of CAT bonds is one of significant importance, however, prior scholars have disproved this aspect under the circumstances of the 2008 financial crisis, e.g. Carayannopoulos and Perez (2015) and Cummins and Weiss (2009), finding significant correlations between CAT bond returns and both equity and high-yield corporate bond market returns. Since the turmoil of the 2008 financial crisis, the CAT bond market has seen significantly revised collateral structures as a means of limiting counterparty risk. Carayannopoulos and Perez (2015) found evidence supporting the theory that new and revised collateral structures may have been able to eliminate investors' perceived counterparty risk as they effectively enhance the credit quality of the collateral and, importantly, limit the types of assets permitted to be invested in under the collateral account.

1.2 Aim & Objective

This research paper aims to explore CAT bonds in their restructured collateral environment following the changes implemented after the 2008 financial crisis, answering whether new collateral structures have ensured that CAT bonds are a zero-beta means of diversification for investors. The subject is explored through the lens of one primary research question, and by utilisation of total return indices to investigate the characteristics of CAT bonds prior to, during, and following the COVID-19 financial crisis. Hence, we evaluate the relationship between CAT bond returns and the returns of stock and corporate bond markets by application of correlation analysis to explore the short-term, and cointegration analysis to extend the analysis to provide a long-term relationship evaluation.

The objective of this study is to investigate CAT bonds from the perspective of an investor. In considering risk-adjusted returns, investors separate risks into idiosyncratic (asset-specific) and systematic (market), earlier scholars have presented that CAT bonds exhibit zero-beta attributes during non-crisis periods, implying insignificant systematic risk. However, found significant correlation during crisis periods by examining the 2008 financial crisis. This paper will discuss the zero-beta aspect in a more recent environment, considering the revised CAT bond market, to explore zero-beta characteristics during the COVID-19 financial crisis.

1.3 Research Question

The research question is developed based on the findings of prior scholars and suggested advancements in research within the field, see Mouelhi (2021). Referring to Chapter 1.2, the primary objective of this paper is to explore CAT bonds in their restructured collateral environment and doing so by answering the question of zero-beta charachteristics. Hence, we formulate the research question as follows:

> D*o CAT bonds exhibit zero-beta characteristics following revised collateral structures prior to, during, and post the COVID-19 financial crisis?*

1.4 Delimitations

This thesis outlines the structure of CAT bonds and makes use of a comprehensive literature analysis to explore CAT bonds' potential to exhibit zero-beta characteristics and present the findings made by prior scholars on the subject.

However, this study's scope is limited to evaluating CAT bonds with respects to two alternative investment classes, the stock and corporate bond markets.

The study takes on a global perspective but makes certain limitations owing to the nature of CAT bonds and their reserved global presence. Moreover, the study is limited to encompass the following periods; pre-crisis (2017.01.01 - 2019.12.31), crisis (2020.01.01 - 2020.12.31), and post-crisis (2021.01.01 - 2023.12.31).

Finally, it should be noted that this study does not aim to investigate the underlying drivers of CAT bond, stock or corporate bond market returns. Rather, this study investigates the potential for CAT bonds as a diversification tool for investors.

2 Literature Review

This chapter explores the existing literature on CAT bonds, develops on primary as well as secondary market pricing, and dives into the findings of prior scholars relating to the correlation and cointegration aspects between CAT bond returns and the returns of stock and corporate bond markets under varying market conditions.

2.1 The Collateral Structure of CAT Bonds

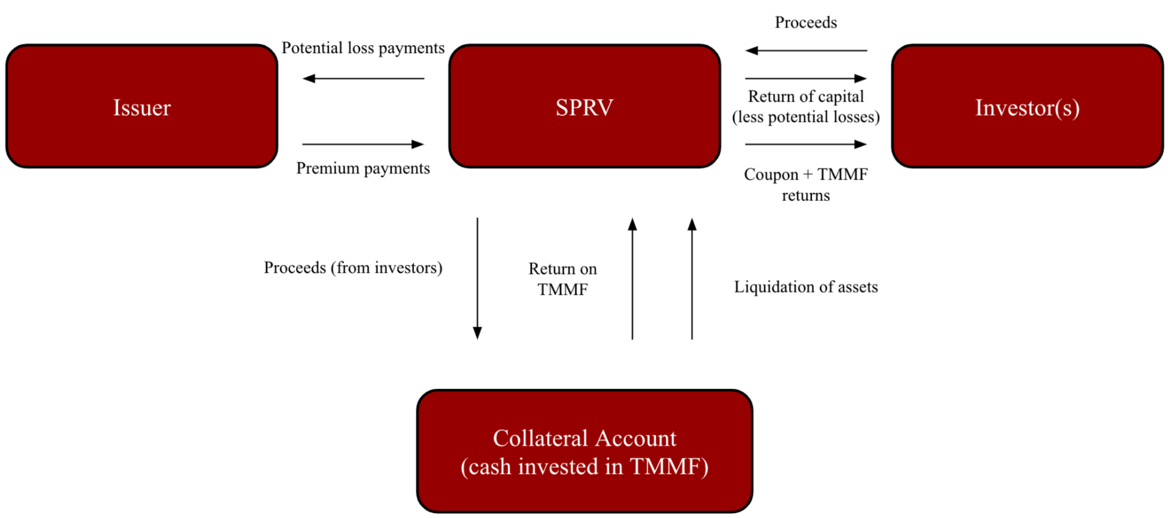

Figure 1 The financial structure of CAT bonds.

Figure 1 depicts the typical collateral structure of CAT bonds today. According to Polacek (2018), the issuer, for example, an insurance company, can transfer insurance risk from its balance sheet onto the capital market by issuing a CAT bond. The Special Purpose Reinsurance Vehicle (SPRV) will manage the cash transfer between the parties, that is, the cash provided by the investors and the premiums paid by the issuer. Moreover, the SPRV will manage the funds such that, in case of a payout being triggered, the funds are available to cover losses incurred by the issuer. The proceeds provided by the investors are typically invested by the SPRV in a

Treasury Money Market Fund (TMMF) that earns the investors a guaranteed return. The returns on the collateral along with the periodic premiums paid by the issuer are subsequently paid to the investors, similar to the coupon payments of traditional coupon bonds.

Carayannopoulos and Perez (2015) develop on how today's structure of CAT bonds is underpinned by a series of revisions implemented after the 2008 financial crisis highlighted significant concerns, particularly regarding the security of the collateral posted by investors. Prior to 2009, when CAT bond issuances resumed after a complete halt in the third quarter of 2008, CAT bonds were often mismatched in the duration of the investments made with the collateral and the duration of the actual CAT bond. Moreover, the investments that made up the collateral account were often Asset-Backed Securities (ABS), for example, Mortgage-Backed Securities (MBS) or Credit Default Obligations (CDOs). Under fairly 'normal' circumstances, these assets yielded great returns, making CAT bonds an attractive investment. However, as ratings on ABS began to decline, the value of the collateral available to be paid to the bond issuer fell significantly. To further complicate the matter, the original investors typically employed a Total Return Swap (TRS) on the collateral account for a guaranteed return on some other benchmark, often the London Interbank Offered Rate (LIBOR). This structure hinged on the vital condition that the TRS counterparty was liable to continuously put up collateral, ensuring that the collateral was marked-to-market. However, this was not the case as TRS counterparties saw very little supervision and additional collateral was seldomly deemed necessary to be put up regardless of fluctuations in the underlying. Collectively, this structure implied severe consequences and a downward spiral when the value of the assets supposed to be backing the collateral fell drastically (Carayannopoulos & Perez, 2015).

The solutions that have been developed and implemented to ensure that the collateral posted is effectively secured, along with better alignment in terms of asset maturities, should, theoretically, ensure that counterparty risk is eliminated. Primarily, the implemented solutions required greater security and supervision in terms of the TRS counterparty, if such was employed, although it is most common to refrain from such nowadays (Braun, 2016), as well as much greater limitations concerning the types of assets permitted to make up the collateral account. Most structured assets, such as MBS and CDOs, would no longer be allowed. Instead, the collateral would only be permitted to be invested in government-backed debt and TMMFs along with putable notes assuming that such was issued by either a sovereign nation or a government-like institution (Carayannopoulos & Perez, 2015). However, it remains almost exclusively the case that TMMFs, for example, short-term U.S. Treasury bills, are employed since these are highlighted by good liquidity and easily observable prices (Braun, 2016).

The threshold that has been agreed upon between the issuer and the investors is known as the bond's attachment point. The concept of the attachment point is central to both parties as it signifies the predefined threshold level of losses that triggers the activation of the CAT bond's risk coverage. Hence, it represents the point at which the bondholder's exposure to losses begins as the threshold determines the minimum losses that must be incurred prior to any payout. Assuming that losses do not exceed the attachment point prior to maturity, the investors are repaid the full collateral originally put forth. However, in the case that a payout is triggered, the funds will be drawn from the collateral account. Hence, the collateral, less any payouts, will be returned to the investors upon maturity. The key takeaway, as depicted in Figure 1, is that the CAT bond is fully collateralised at all times, implying zero risk of default following the principle that the collateral is managed by the SPRV as an intermediary and invested in short-term and practically secure assets.

A CAT bond typically faces the possibility of being triggered in one of three possible scenarios; *Indemnity triggers*, similar to traditional reinsurance, will base any bond payouts on the actual losses incurred by the issuer. *Industry loss triggers* will employ a third-party investigator to determine the aggregate losses incurred by the insurance industry at large as a predetermined level (attachment point) of the industry's losses will dictate the bond's payout to the issuer. *Parametric triggers* will base payouts on a specified level of catastrophe, for example, the magnitude of an earthquake (Polacek, 2018). In summary, the aforementioned indemnity trigger is the most commonly applied in CAT bond issuances today, making up approximately 67% of the outstanding CAT bonds (Artemis, 2024).

2.2 Pricing CAT Bonds in the Primary Market

The following paragraph outlines the empirical findings on factors that determine the pricing of CAT bonds upon issuance. A basic understanding of the conceptual framework is essential to comprehend the market for CAT bonds.

Thus far, Braun (2016) has studied the most comprehensive CAT bond data set, comprising 466 tranches issued between June 1997 and December 2012 to determine the pricing factors in the primary market for CAT bonds. Braun finds that the expected loss is the single most influential determinant of the spread in CAT bonds upon issuance. This finding was expected as CAT bonds are in practice very similar to traditional reinsurance contracts, where the expected loss has proven to be the greatest spread determinator by a multitude of literature, following that it is effectively the best estimator of risk. Moreover, Braun finds that the covered territory has a significant pricing role whereby it refers to the geographical area in which the CAT bond covers losses. Braun reveals that bonds issued to cover losses in the U.S. carry the highest average spread, greatest risk premium and the largest multiple of the spread-to-expected loss ratio, followed by bonds issued to cover multiple territories. Additionally, Braun's findings suggest that the sponsor, reinsurance cycle and the spread of the BB corporate bond index are noteworthy drivers of the CAT bond spreads as well. Conversely, Braun suggests that issue volume, trigger type (Indemnity, Industry loss or Parametric) along with the peril (type of catastrophic event(s) covered) play only a very minor role. Somewhat surprisingly, the term of the CAT bond does not seem to affect spreads at all.

2.3 Pricing CAT Bonds in the Secondary Market

Although this thesis does not aim to derive the drivers of market premiums of CAT bonds in the secondary market, it is important to understand and summarise prior findings of such drivers to provide a comprehensive review of the CAT bond market and its interaction with other financial markets.

Gürtler, Hibbeln and Winkelvos (2016) suggest that the relationship between financial crises and the market for CAT bonds is somewhat unclear, however, fundamentally building upon two possibilities. Either, the CAT bond market remains independent of any events occurring in the capital market(s) since CAT bonds offer protection against natural disasters that, theoretically, are independent of any events in the capital market(s). Comparatively, Gürtler et al. suggest that there might also be a case in which a general increase in risk aversion by market participants forces the CAT bond market to co-move with the capital market(s).

Gürtler et al. (2016) studied secondary CAT bond market data between 2002 and 2012, placing a special emphasis on both Hurricane Katrina, which struck in 2005, as well as the 2008 financial crisis. Relating to Hurricane Katrina, Gürtler et al. found that the premiums for hurricane perils increased drastically following Katrina's devastation. The significant increase in CAT bond premiums could be attributed to severe increases in expected losses following calculations made by third-party modellers. Moreover, this increase suggests that there existed a lack of trust in expected loss calculations made by such third parties after Hurricane Katrina. Hence, the capital market required greater risk premiums following an increased expected loss multiple after Katrina, although such multiples were only found to be significant for hurricane perils. Comparatively, relating to the 2008 financial crisis, Gürtler et al. focus on the default of Lehman Brothers. Their findings indicate that the bankruptcy of Lehman Brothers resulted in an absolute increase in risk premiums. Furthermore, their findings of expected losses as a determining factor of variance in secondary market prices reveal that 79% of the variance in premiums was explained by the expected loss prior to Katrina in 2005. However, between Katrina and the collapse of Lehman Brothers in 2008, the explanatory power of the expected loss fell to 57%. Post the Lehman Brothers bankruptcy, this number dropped to 37%.

Further findings by Gürtler et al. (2016) relate to Hurricane Ike which struck the U.S. in September 2008, occurring around the time of the Lehman Brothers collapse. In observing CAT bond premiums, Gürtler et al. found that, in consistency with Hurricane Katrina, expected losses for hurricane perils increased, however, not nearly as drastically as they did in 2005. These findings indicate that investors may have adjusted their perceived risk of hurricane perils for the long-term already after Hurricane Katrina.

2.4 The Zero-Beta Concept

The concept of "zero-beta" is extensively debated in the empirical literature. We apply the term's definition as specified by Artemis (2024); "*An investment which doesn't correlate with an index or market results and is designed to have zero systemic risk*." However, the definition is somewhat complicated owing to the concept of systemic risk. The European Central Bank (ECB) acknowledges the lack of a commonly accepted definition of the concept, however, presents that one definition is the risk of experiencing a severe systemic event. Such an event is explained to have two possible triggers, an exogenous shock, either idiosyncratic (limited) or systematic (widespread). An alternative is for the event to arise endogenously (from within the financial system) (European Central Bank, 2009). In the pursuit of empirical findings on CAT bonds as potential zero-beta investments, we focus on the correlation aspect, both in the short- and long-term. This follows the interpretation taken by prior scholars, e.g. Mouelhi (2021). Hence, we do not devote ourselves to focusing on the underlying systemic risk factor in greater detail. Thus, the interpretation of zero-beta is that of an asset which generates returns independent of a comparable market index.

2.5 Empirical Evidence of CAT Bonds as Zero-Beta

Cummins and Weiss (2009) found that CAT bonds were highly correlated with the yields of the LIBOR and U.S. government bonds. These findings were expected as both LIBOR and U.S. government bonds commonly made up the baseline reference in CAT bond pricing. Findings of greater significance by Cummins and Weiss related to CAT bond returns being virtually uncorrelated with the returns on alternative investments, including stock and corporate bond markets. These conclusions were drawn based on a sample period of January 2002 through June 2007.

Investigating the period of the 2008 financial crisis, Cummins and Weiss (2009) found that the returns on the CAT bond index significantly correlated with the returns of the S&P 500 and corporate bond indices. Hence, concluding that CAT bonds were only to be regarded in terms of being a zero-beta investment class under non-crisis periods.

Carayannopoulos and Perez (2015) study the subprime financial crisis similar to Cummins and Weiss (2009). However, approaching CAT bonds from a perspective of diversification. Per the findings by Cummins and Weiss during non-crisis, 'normal' periods, Carayannopoulos and Perez state that *"...we find evidence that the effects of the financial crisis on CAT bonds disappear by the beginning of 2011, as the correlations with the market returned to their statistically insignificant pre-crisis levels. These results may imply that the new and improved collateral structures created for CAT bonds issued after 2009 have been perceived as effective by market participants."* The conclusion drawn by Carayannopoulos and Perez presents clear and concise evidence that CAT bonds were exposed to systematic risk during the subprime financial crisis. However, their findings of the transition from an evident correlation structure to a non-significant correlation following the crisis period suggest that revisions made to the CAT bond market may enable CAT bonds to be regarded as zero-beta in future crisis periods.

Mouelhi (2021) takes a comprehensive approach to the long-term period following the 2008 financial crisis by studying both correlation and cointegration between CAT bonds and several alternative indices between 2012 and 2019. In summary, Mouelhi found only weak correlations between CAT bonds and stock- and corporate bond markets over the whole period, this indicates some, but not extensive, short-run dependencies under 'normal' circumstances.

Additionally, by examining the long-term relationship through the application of cointegration analysis, Mouelhi found no existence of any long-term relationship between CAT bonds and stock- or corporate bond markets. Hence, Mouelhi concludes that CAT bonds are partially zero-beta in the short run, but entirely zero-beta over the long run under non-crisis circumstances.

2.6 Hypothesis Development

The findings presented in the preceding literature review form the basis of the derived hypotheses. Ultimately, Gürtler et al. (2016) state that dependency structures revealed in the 2008 financial crisis suggest that correlations exist between CAT bonds and other securities. Moreover, such correlations have the potential to increase during extreme financial conditions when investors typically strive for the benefits of diversification. Additionally, Cummins and Weiss (2009) revealed that correlations between the returns of the S&P 500, corporate bond indices and CAT bonds exist under crisis periods, however, are insignificant under 'normal' circumstances. Similarly, Carayannopoulos and Perez (2015) presented evidence of correlation during the subprime financial crisis. In addition to these findings, Mouelhi (2021) conclude CAT bonds to be zero-beta in the long run, however, carry short-term correlation with alternative assets, by examining the period from 2012 through 2019.

Collectively, the findings by Cummins and Weiss (2009), Carayannopoulos and Perez (2015), as well as Gürtler et al. (2016), suggest that CAT bonds should not be regarded as a zero-beta investment as the CAT bond market exhibited a correlation with both the stock and corporate bond markets during the period of the subprime financial crisis. However, findings by Carayannopoulos and Perez (2015) and Mouelhi (2021) of the post-crisis period, as well as

Cummins and Weiss's (2009) pre-crisis findings support the theory that CAT bonds could be viewed as zero-beta with regards to stock and corporate bond markets under 'normal' market conditions. Hence, in light of the revised collateral structures presented throughout this thesis, ultimately implemented to counter the shortcomings found by prior researchers, the following hypotheses have been formulated.

Null hypotheses, correlation in the pre-crisis period:

H_1 *CAT bond returns are uncorrelated with corporate bond market returns.*

H_2 *CAT bond returns are uncorrelated with stock market returns.*

Null hypotheses, correlation in the crisis period:

H_1 *CAT bond returns are uncorrelated with corporate bond market returns.*

H_2 *CAT bond returns are uncorrelated with stock market returns.*

Null hypotheses, correlation in the post-crisis period:

H_1 *CAT bond returns are uncorrelated with corporate bond market returns.*

H_2 *CAT bond returns are uncorrelated with stock market returns.*

Null hypotheses, cointegration:

H_1 *The CAT bond market is not cointegrated with the corporate bond market.*

H_2 *The CAT bond market is not cointegrated with the stock market.*

3 Methodology & Data Description

The following chapter will describe the empirical approach in greater detail, explaining the methodology utilised to test the stated hypotheses.

The data is gathered from Bloomberg, S&P Capital IQ and Refinitive Eikon (LSEG). Following scrutinisation, no inconsistencies or missing values were found.

The hypotheses will be evaluated using correlation analysis, consisting of both Pearson Correlation Coefficient (PCC) as well as Spearman's Rank Correlation Coefficient (SRCC), and cointegration analysis by application of the Engle-Granger Cointegration test. This approach follows the suggested advancements in research by Mouelhi (2021).

3.1 Variables

The thesis utilises the following four indices in its investigative approach to the research question.

Swiss Re Global Cat Bond Performance Index, *Bloomberg Ticker: SRGLTRR* is a non-investable index tracking the aggregate performance of all CAT bonds that are issued under Rule 144A, capturing bonds denominated in any currency, both rated and unrated, outstanding perils as well as triggers. The index is not subject to currency risk as potential risks relating to non-US-denominated CAT bonds are hedged at the bond's inception. At the bond's settlement date, its notional value is converted from its currency of issuance to USD. The index has tracked CAT bond performance since 2007, it is the most frequently updated CAT bond performance index, as it is updated weekly (Swiss RE, 2014).

ICE BofA BB U.S. High Yield Total Return Index, Bloomberg Ticker: H0A1 is an appropriate corporate bond index following the logic of Cummins and Trainar (2009) as they suggest that comparative corporate bonds, to CAT bonds, are rated BB. The index is a subset of the ICE BofA U.S. High Yield Master II Index and tracks the performance of below-investment-grade U.S. dollar-denominated corporate debt publicly issued in the U.S. domestic market, including all securities given a BB rating (Federal Reserve Bank of St. Louis, 2024). It is deemed appropriate to employ a U.S. dollar-denominated corporate bond index as a significant majority of CAT bonds are issued in the U.S. (OECD, 2024). Additionally, by benchmarking against a total return index, we account for the compounding effect of reinvesting coupon payments over time.

S&P 500 Total Return Index, Bloomberg Ticker: SPXTR is used to proxy the capital market. The index is commonly regarded to be the best single gauge of large-cap U.S. equities as it includes the 500 leading corporations, covering approximately 80% of the total market capitalisation. Additionally, in coherence with the aforementioned, it is deemed most reasonable to employ a U.S.-based index, as well as utilise the total return of such to account for reinvestments of dividends over time (S&P Dow Jones Indices, 2024).

ICE U.S. Treasury Bill 3-Month Index, Bloomberg Ticker: ITB3 is utilised to proxy the risk-free interest rate. The index is market-value weighted and consists of U.S. Treasury-issued debt, excluding Inflation-linked securities, Floating Rate Notes, Cash Management Bills, and any government agency debt issued with or without a government guarantee. Maturities are most commonly equal to three months. However, the index may include maturities that are one month at minimum, but less than or equal to one year at maximum (ICE Indices, 2024). Referring to Chapter 2.1, we chose not to include this index in either correlation or cointegration analysis as it typically is integrated into the collateral structure and hence comprises part of the CAT bonds returns. The relationship with the CAT bond market has also been proven by prior scholars, see Chapter 2.5, Cummins and Weiss (2009).

All index data has been gathered weekly to ensure consistency with the Swiss Re Global Cat Bond Performance Index. We refer to the Appendix for a complete visualisation of all indices.

3.2 Data

To provide a comprehensive review, this study utilises data on the returns of the CAT bond, stock and corporate bond markets during 7 years, beginning January 1st 2017 and commencing on the 31st of December 2023. This period is deemed to represent the best reflection of the revised collateral structure environment of CAT bonds following the reasoning of Carayannopoulos and Perez (2015). Additionally, it is deemed most accurate regarding the market environment that dictates CAT bonds in terms of size and maturity at present.

This thesis will define the crisis period investigated as beginning on January 1st 2020, and commencing on December 31st 2020. The literature ranges in its specification on the best definition of what defines the precise COVID-19 financial crisis period. However, as researchers, we have identified this specific period's range by analysing the reported responses and actions taken by the Bank for International Settlements (BIS), see BIS Annual Report 2020/21, and statistics presented by The Committee for the Coordination of Statistical Activities (CCSA) COVID-19 report (2021). Hence, the study is divided into three periods, pre-crisis (2017.01.01 - 2019.12.31), crisis (2020.01.01 - 2020.12.31), and post-crisis

(2021.01.01 - 2023.12.31). In total, we collect 413 observations for each index, 178 in the pre-crisis period, 59 in the crisis period, and 176 in the post-crisis period.

3.3 Data Analysis

The data analysis consists of a twofold approach, firstly, we calculate the correlation coefficients between the CAT bond index and stock market index, as well as the CAT bond index and corporate bond market index. This process is completed for each respective period separately. Secondly, we study the sample period in full through cointegration analysis.

Preceding any statistical inferences, we examine the data by descriptive statistics and visualisation. Hence, we calculated the mean, median, standard deviation, minimum and maximum values as well as the Sharpe ratio for each index in the respective period. This allows for an enhanced understanding and a holistic overview of the data. For this purpose, as well as the preceding correlation analysis, the original data has been transformed into weekly percentage returns following the formula in Equation 1:

$$\frac{(V_t - V_{t-1})}{V_{t-1}} \times 100 \qquad \textbf{(1)}$$

3.4 Correlation Approach

The correlation analysis builds primarily on Spearman's Rank Correlation Coefficient (SRCC). Following Brooks (2019), we deem SRCC as a non-parametric correlation estimator to be superior compared to parametric alternatives (Pearson Correlation Coefficient (PCC)) which require our time-series data to follow a normal distribution. However, we chose to include PCC owing to common practice among prior scholars. Hence, we compute PCC and SRCC between the CAT bond index, corporate bond index and stock market index for each respective period. We conduct all calculations relating to the correlation analysis by application of Python.

3.5 Cointegration Approach

The Engle and Granger (1987) approach to cointegration forms the foundation for this thesis cointegration analysis, although the application of Engle and Granger's original approach is condensed following Brooks (2019). Brooks states that a linear combination of variables integrated of order one (I(1)) will itself be I(1). However, a linear combination of variables that are I(1) will be stationary (I(0)) if these variables are cointegrated. Another comprehensive, yet somewhat condensed, definition of the concept of cointegration is provided by Harris (1996) who states that even in the case that time series themselves are inclusive of a stochastic trend, they will move together over time if the series are linked through some equilibrium relationship. Hence, put simply, the CAT bond market is said to be cointegrated with the corporate bond market and/or stock market if any linear combination of such time series is stationary. Brooks explains this phenomenon as owing to the principle that many time series are non-stationary, however, they may move together, in the long-run, due to an external influence that affects the time series (e.g. market forces). The emphasis in the distinction from correlation is that variables may be cointegrated as they share a long-run equilibrium relationship, although they deviate in their relationship in the short term.

Referring to the logic of a cointegration relationship outlined in the preceding paragraph, one important prerequisite for cointegration analysis is that the time series are, individually, $I(d)$ non-stationary as elaborated on by Noriega and Ventosa-Santaulària (2012). This implies that we need our time series to be stationary as they are integrated of the same order (d). Hence, we begin by checking if the original data of each respective index is non-stationary by application of the Augmented-Dickey Fuller (ADF) test. Additionally, we ensure that the data does become stationary as we take the first difference of each respective time series.

Following the approach of Brooks (2019), we begin by testing the null hypothesis $\phi = 1$ against the alternative $\phi < 1$ in Equation 2:

$$y_t = \phi y_{t-1} + u_t \qquad \textbf{(2)}$$

In simpler terms, the null hypothesis states the inclusion of a unit root in the time series (it is non-stationary), and the alternative hypothesis states that the time series is stationary (does not include a unit root). We complete this process for the whole sample period. Thereafter, we compute the first difference of each respective time series and conduct the ADF test once more. This evaluates the $I(1)$ non-stationary assumption and allows us to conclude if our data is suited to the Engle-Granger approach of cointegration analysis.

Engle & Granger's approach to cointegration is two-fold, the first step consists of an OLS estimation of the regression:

$$Y_t = \alpha + \beta X_t + \varepsilon_t \quad \textbf{(3)}$$

$Y_t = SRGLTRR\ at\ week\ t$

$X_t = SPXTR/H0A1\ at\ week\ t$

$\varepsilon_t = error\ term$

α & $\beta = OLS\ regression\ parameters\ subject\ to\ estimation$

In the first step, we aim to extract the estimated error terms $(\hat{\varepsilon}_t)$ such that:

$$\hat{\varepsilon} = Y_t - \hat{\alpha} - \hat{\beta} X_t \qquad \textbf{(4)}$$

To ensure that the optimal number of lags K* is obtained, we employ the Bayesian Information Criterion (BIC). We deem BIC to be well suited to this application as it effectively penalises models including too many lags (K), moreover, it is found more consistent by prior scholars (Mouelhi (2021) as compared to alternatives, e.g. Akaike Information Criterion (AIC) in this specific scenario. Hence, we apply BIC on two occasions, firstly in the OLS estimation, and secondly, in our ADF test on the residuals extracted from the OLS equations. We conduct all calculations relating to the cointegration analysis by application of Python.

The analysis of our cointegration test will follow such that; in the scenario in which we cannot reject the hypothesis $\gamma = 0$, we can conclude that the residuals of our respective OLS models incorporate a unit root, meaning that they are non-stationary, which implies that there will be no cointegrated relationship between our variables. In other words, we conclude that there exists, alternatively, does not exist, any long-run equilibrium relationship between the CAT bond market and the stock market, as well as the CAT bond market and the corporate bond market under our period of analysis.

4 Empirical Analysis

This section will depict the empirical findings of the correlation and cointegration approaches respectively. Throughout the empirical analysis, we apply a 95% confidence interval, however, report findings under the 90% and 99% confidence intervals to enhance the understanding of the empirical findings. Initially, we present the summary statistics of our respective variables.

4.1 Data Evaluation

In Table 1, we observe the mean, median, standard deviation, minimum and maximum values as well as the Sharpe Ratio for our respective variables. We calculated the Sharpe Ratio following Brooks (2019) as the mean return less the risk-free rate proxied by the 3-month treasury bill (ITB3) and then divided by the standard deviation of the respective index returns.

Full Period 1/6/2017 - 12/29/2023						
	Mean	**Median**	**Std. Dev.**	**Min**	**Max**	**Sharpe Ratio**
SRGLTRR	0.089	0.110	1.086694	-15.303	10.65853	0.0552466
SPXTR	0.229	0.303557	2.384356	-14.9601	12.132	0.08367543
H0A1	0.079	0.106488	1.013248	-9.74364	5.543893	0.04916951
ITB3	0.029	0.022	0.032	-0.031	0.195	
Pre-Crisis 1/6/2017 - 12/31/2019						
	Mean	**Median**	**Std. Dev.**	**Min**	**Max**	**Sharpe Ratio**
SRGLTRR	0.056	0.084	1.433733	-15.303	10.659	0.01991406
SPXTR	0.233	0.294	1.616657	-7.036	4.447	0.12692515
H0A1	0.104	0.106	0.395359	-1.833	1.764	0.1914689
ITB3	0.028	0.028	0.016	-0.031	0.066	
Crisis 1/3/2020 - 12/31/2020						
	Mean	**Median**	**Std. Dev.**	**Min**	**Max**	**Sharpe Ratio**
SRGLTRR	0.096	0.102	0.247348	-0.970	0.605	0.344165
SPXTR	0.365	0.752	4.175276	-14.960	12.132	0.08485907
H0A1	0.163	0.202	2.102383	-9.744	5.544	0.07212403
ITB3	0.011	0.003	0.02854	-0.015	0.195	
Post-Crisis 1/8/2021 - 12/23/29						
	Mean	**Median**	**Std. Dev.**	**Min**	**Max**	**Sharpe Ratio**
SRGLTRR	0.120	0.131	0.822121	-9.653	2.391	0.10168931
SPXTR	0.178	0.282	2.222629	-5.760	6.611	0.06368277
H0A1	0.026	0.085	0.886366	-2.768	3.358	-0.0122137
ITB3	0.037	0.012	0.042	-0.025	0.161	

Table 1 Descriptive statistics of weekly percentage returns including the mean, median, standard deviation, minimum and maximum values as well as the Sharpe Ratio.
The Sharpe Ratio equals the mean return less the risk-free rate, then divided by the standard deviation.

In observing the full period, we conclude that the best risk-adjusted return is found in the S&P 500 Total Return Index (SPXTR). Concerning the pre-crisis period, we draw the same conclusion for the ICE BofA BB U.S. High Yield Total Return Index (H0A1). During the crisis period in question, we find that the Swiss Re Global Cat Bond Performance Index (SRGLTRR) outperformed both alternative indices relatively significantly, this is true for the post-crisis period as well.

In Figure 2, we observe the weekly percentage returns of our respective indices, visually depicting the numbers presented in Table 1.

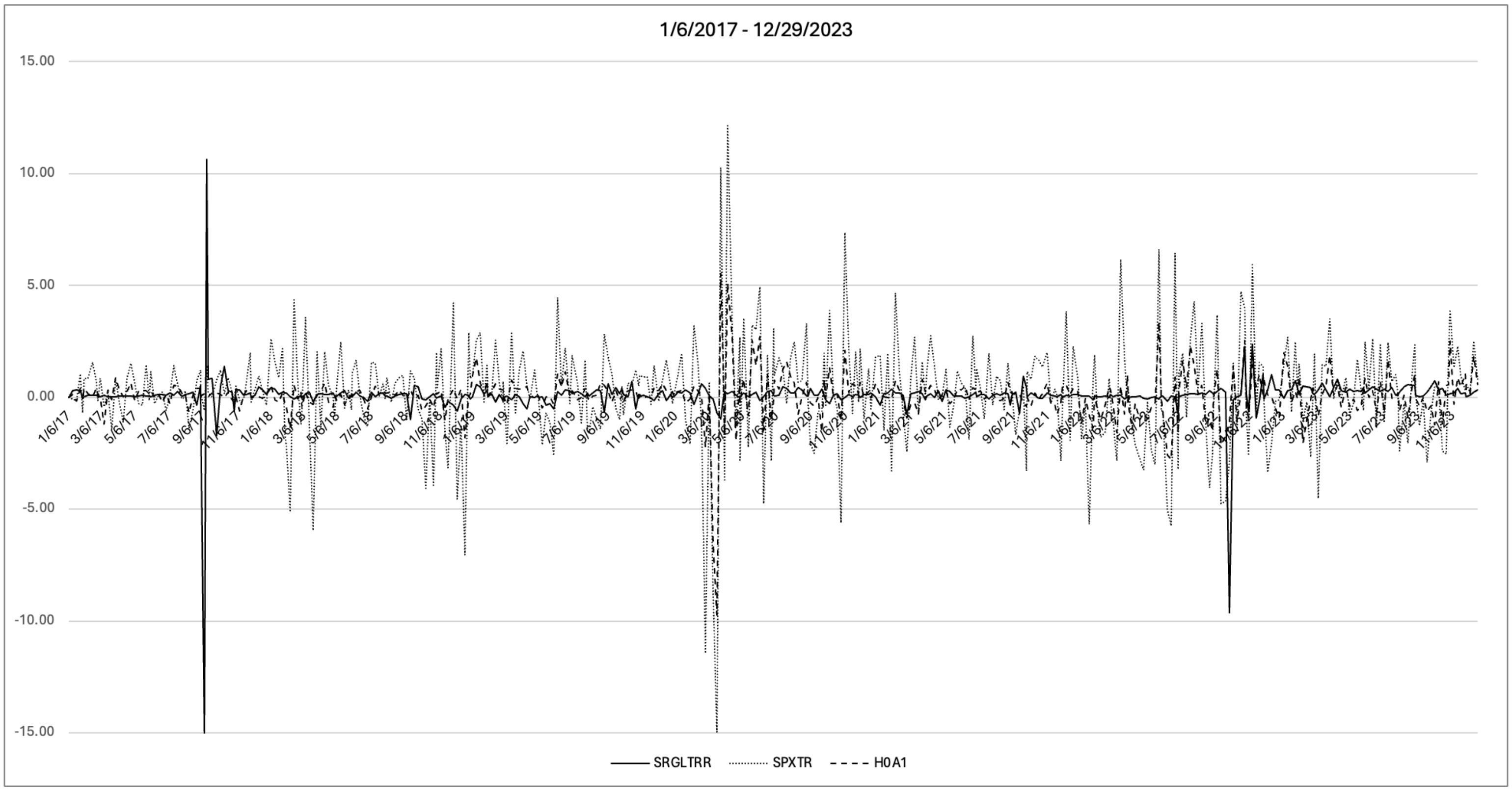

Figure 2 Weekly percentage returns of the SRGLTRR, SPXTR & H0A1 for the complete sample period (1/6/2017 - 12/29/2023).
Source Bloomberg, S&P Capital IQ.

Following a visual interpretation of Figure 2, it is evident that the SRGLTRR is, comparatively, unaffected in terms of volatility during the crisis period. However, potential explanations for the extensive volatility observable around the third quarter of 2017 relate to the Atlantic Hurricane Season, which typically ranges from June 1st until November 30th. According to Feltgren (2017), the 2017 Atlantic Hurricane season was extremely severe, producing not only 10 hurricanes, but for the first time in history, as many as three category 4 hurricanes made landfall in the U.S. Additionally, we note the sudden plunge around the third quarter of 2022 which, similar to 2017, follows the Atlantic Hurricane Season. Particularly, we observe that this negative return development corresponds to Hurricane Ian, which caused an estimated $112 billion in damages between September 23rd and September 30th, 2022 according to the National Hurricane Centre (2023). Although a more detailed study of the underlying return drivers lay outside the realm of this thesis, we may conclude that the volatility in weekly percentage returns observable for the SPXTR and H0A1 seem to follow each other reasonably well, meanwhile, the returns observable in the SRGLTRR seem to have no particular co-movement with these indices. Moreover, relating to the potential drivers of secondary market prices for CAT bonds, our findings seem to align with such findings made by Gürtler et al. (2016). Hence, we may conclude that the market price of CAT bonds appears vulnerable to catastrophic weather events.

In summary, these findings support CAT bonds as a means of diversification, especially in crisis periods as we conclude that they offer the greatest risk-adjusted return as measured by the Sharpe Ratio. For a detailed visualisation of the respective index returns, we refer to the Appendix.

4.2 Correlation Evaluation

Table 2 presents the PCC and SRCC for the respective periods and the corresponding p-values. The decision criteria follow that we reject the null hypothesis if we find the p-value to be smaller than the level of significance.

Pre-Crisis		
Pearson Correlation		
	SPXTR	**H0A1**
SRGLTRR	0.080075704	0.003362603
p-value	0.28799804	0.964468572
Spearman's Rank Correlation		
SRGLTRR	0.094765668	-0.002684245
p-value	0.208298513	0.97163316
Crisis		
Pearson Correlation		
	SPXTR	**H0A1**
SRGLTRR	-0.075407764	0.043926446
p-value	0.570283381	0.741138705
Spearman's Rank Correlation		
SRGLTRR	-0.139976622	-0.116949153
p-value	0.290332401	0.377714284
Post-Crisis		
Pearson Correlation		
	SPXTR	**H0A1**
SRGLTRR	0.177804748	0.15989308
p-value	0.018569188**	0.034545498**
Spearman's Rank Correlation		
SRGLTRR	0.078172862	0.041643529
p-value	0.303811908	0.584253963

Table 2 Pearson correlation coefficients and Spearman's rank correlation coefficients.
The null hypothesis is that the correlation coefficient is equal to zero, the alternative hypothesis is that the correlation coefficient is different from zero.
P-values of correlation coefficients marked with (***), (**) and (*) reject the null hypothesis at a significance level of 1%, 5% and 10% respectively following that the p-value is less than the specified significance level.

At the 1%, 5% and 10% levels respectively, we accept the null hypotheses H_1 and H_2 for the pre-crisis period as we find no statistically significant correlation between either SRGLTRR and SPXTR or SRGLTRR and H0A1. Likewise, concerning the crisis period, we accept the null hypotheses H_1 and H_2. Moreover, in terms of SRCC, we find no significant relationship during the post-crisis period either. However, we note that we reject the null hypothesis H_1 and H_2 under Pearson correlation as the coefficients between both SRGLTRR and SPXTR, as well as SRGLTRR and H0A1 are significant at the 10% and 5% levels respectively.

Generally, there appears to be no exact definition in the literature of what constitutes a considerate enough correlation coefficient to qualify as either weak, moderate or strong. However, adhering to Mouelhi (2021), we chose the levels such that coefficients equal to or greater than 0.70 qualify as strong correlation, coefficients ranging from 0.20 to 0.70 qualify as moderate correlation, and coefficients equal to or below 0.20 qualify as weak correlation. Hence, we conclude that the relationships found in the post-crisis period are to be regarded as weak, although statistically significant, as neither relationship exceeds a correlation coefficient equal to 0.20 or greater.

4.3 Cointegration Evaluation

Table 3 presents the ADF test statistics and corresponding p-values for the evaluation of the stationarity of our original data. The null hypothesis of this test states the inclusion of a unit root, implying non-stationarity. Alternatively, our variables are $I(0)$.

Full Period 1/6/2017 - 12/29/2023		
	ADF statistic	**p-value**
SRGLTRR	-2.782*	0.061
SPXTR	-1.246	0.653
H0A1	-0.696	0.848

Table 3 Augmented Dickey-Fuller test for stationarity of original variable data.
The null hypothesis is that the time series includes a unit root, the alternative hypothesis is that the time series does not include a unit root.
ADF statistics marked with (***), (**) and (*) reject the null hypothesis at a significance level of 1%, 5% and 10% respectively following that the ADF statistic is less than the corresponding critical value.

We fail to reject the null hypotheses as ADF statistics are greater than the respective critical values of -3.446, -2.869 and -2.57 at 1%, 5% and 10% levels respectively, with the exception of the SRGLTRR at the 10% level. Additionally, p-values are effectively greater than 0.05.

We differentiate our original data once to ensure that all variables are $I(1)$ non-stationary, implying that the desired outcome in this test is for our data to exhibit stationarity.

Full Period 1/6/2017 - 12/29/2023		
	ADF statistic	**p-value**
SRGLTRR	-17.759***	0.000
SPXTR	-21.104***	0.000
H0A1	-10.841***	0.000

Table 4 Augmented Dickey-Fuller test for stationarity of differentiated data.
The null hypothesis is that the time series includes a unit root, the alternative hypothesis is that the time series does not include a unit root.
ADF statistics marked with (***), (**) and (*) reject the null hypothesis at a significance level of 1%, 5% and 10% respectively following that the ADF statistic is less than the corresponding critical value.

From Table 4, it is implied that the data meets the prerequisites for the application of the Engle-Granger cointegration test. We draw this conclusion as we reject the null hypotheses following that each ADF statistic is smaller than the respective critical values of -3.446, -2.869 and -2.571 at 1%, 5% and 10% respectively, moreover, p-values are effectively equal to zero. Hence, we conclude that our original data is $I(1)$ non-stationary, satisfying our prerequisites. Following this conclusion, we proceed by determining the optimal lag order K*.

Optimal Lag Order		
	SPXTR	**H0A1**
SRGLTRR	4	4

Table 5 Optimal lag order determined under BIC for OLS equations.

We apply BIC to determine the optimal lag order (K*). Under our model specification, K* is the minimum lag order with the possible range specified as 1 - 5. The outcome of our BIC model results in four lags as the optimal lag order for each respective OLS regression as displayed in Table 5. Owing to the principle that the Engle-Granger cointegration approach focuses on the residuals of the estimated OLS regressions, we do not present our OLS statistics in greater detail.

Table 6 displays the optimal lag order for the ADF test on the residuals estimated by our OLS regressions. We implement the possible range specified as 1 - 5 and find one lag to be optimal.

Optimal Lag Order		
	SPXTR	**H0A1**
SRGLTRR	1	1

Table 6 Optimal lag order determined under BIC for ADF tests.

Table 7 displays the results of the ADF test for stationarity of the residuals extracted from the preceding OLS regressions. We employ the optimal lag order determined under BIC as displayed in Table 6. Previously, we outlined that failing to reject the null hypothesis ($\gamma = 0$) under the ADF test implies that the residuals of the OLS regressions incorporate a unit root and are thus non-stationary. Consequently, if ADF statistics are less than the corresponding critical values, the residuals are stationary and suggest the presence of a long-run equilibrium relationship between the two variables.

Augmented Dickey-Fuller Test for Stationarity		
	SRGLTRR/SPXTR	**SRGLTRR/H0A1**
ADF statistic	-3.246**	-2.733*
p-value	0.0175	0.0685

Table 7 Augmented Dickey-Fuller test for stationarity of residuals.
The null hypothesis is that the time series includes a unit root, the alternative hypothesis is that the time series does not include a unit root.
ADF statistics marked with (***), (**) and (*) reject the null hypothesis at a significance level of 1%, 5% and 10% respectively following that the ADF statistic is less than the corresponding critical value.

For the relationship between SRGLTRR and H0A1, it follows, based on the critical values of -3.446, -2.869 and -2.57 at 1%, 5% and 10% levels respectively, that we reject the null hypothesis at the 10% significance level as our ADF statistic (-2.733) is smaller than the corresponding critical value (-2.57). The p-value of 0.0685 is greater than our significance level of 0.05, implying that we fail to reject the null hypothesis of a unit root. Hence, this allows us to confirm H_1, the CAT bond market exhibit no long-run equilibrium relationship with the corporate bond market.

Concerning the relationship between SRGLTRR and SPXTR, we find that our ADF statistic (-3.246) is smaller than the respective critical values at the 5% (-2.869) and 10% (-2.57) levels of significance, however, greater than our critical value at the 1% (-3.446) level of significance. Hence, we reject the null hypothesis at the 5% and 10% levels respectively, indicating that our residuals are stationary. Moreover, the adhering p-value equal to 0.0175 is less than our significance level. Hence, it leads us to reject H_2, concluding that the CAT bond market does indeed share some long-run equilibrium relationship with the stock market.

5 Conclusions

To summarise our correlation findings, we accept the null hypothesis of no significant correlation relationship between the variables SRGLTRR and SPXTR during either the pre-crisis or crisis periods. The same conclusion is drawn regarding the relationship between the variables SRGLTRR and H0A1 over the corresponding periods. However, we reject the null hypotheses under PCC for the post-crisis period in terms of both the relationship between SRGLTRR and SPXTR as well as SRGLTRR and H0A1. Although, we emphasise that we do not reject such hypotheses under SRCC. These findings are partially consistent with those made by Mouelhi (2021) in that weak, although statistically significant, correlations were found between CAT bonds and the stock and corporate bond markets from 2012 to 2019. However, we do not find any significant correlation during either pre-crisis or crisis periods. This leads us to consider the potential for such a correlation relationship in the post-crisis period to be spurious. Moreover, referring to the absence of any correlation, especially in the crisis period, our findings highlight the potential for CAT bonds as a means of diversification for investors. Additionally, we shall not dismiss the importance of the risk-adjusted return measured by the Sharpe Ratio during the crisis period whereby the risk-adjusted returns of the CAT bond market significantly outperformed both our proxies for the stock and corporate bond markets.

The findings we present relating to the concept of cointegration are, to an extent, contradictory to those presented by Mouelhi (2021). Meanwhile, Mouelhi found no significant cointegration relationship between the CAT bond and corporate bond market, or the CAT bond and stock market, we prove that there exists at least some relationship between such variables when the investigated period is extended to include a crisis period. In conclusion, we find evidence to support the theory that the CAT bond market does not share any long-run equilibrium relationship with the corporate bond market. However, we do find evidence that points toward a long-run equilibrium relationship between the CAT bond market and the stock market.

To evaluate the potential for CAT bonds as a diversification tool, we return to the research question; *Do CAT bonds exhibit zero-beta characteristics following revised collateral structures prior to, during, and post the COVID-19 financial crisis?* Our results show that we can label CAT bonds as zero-beta under the pre-crisis and the crisis periods. However, we find inconclusive evidence of CAT bonds as zero-beta under the post-crisis period. Concerning the long-term perspective, referring to Harris's (1996) definition of cointegration, we find that the CAT bond market is independent only with regard to the corporate bond market. Moreover, we find that there exists a long-term equilibrium relationship between the CAT bond market and the stock market. Hence, CAT bonds are, in the long-term, not sufficiently independent of the stock market to be regarded as zero-beta. As such, the CAT bond market appears to remain subject to some degree of systematic risk.

For investors, our findings indicate the potential for CAT bonds as a means of diversification, especially from the perspective of fixed-income securities, as we find no significant cointegration relationship between the CAT bond market and the corporate bond market. Importantly, the absence of any crisis period correlation relationship highlights the potential for CAT bonds in a diversified investment strategy.

6 Future Research

The state of the climate is extensively debated, likely owing as much to empirical uncertainties as to politically rooted views on the question. However, researchers appear to agree that natural disasters of varying kinds are becoming more costly, not necessarily owing to their nature, but to the fact that population density in regions especially susceptible to harm is increasing, for example, see Philbrick and Wu (2022) as well as Dapena (2018). Seeing as the growing costs of natural disasters appear to be a fact, rather than a theory, the outlook for the CAT bond market and its potential growth appears bright. Hence, we suggest a general development of research investigating CAT bonds as an investment, for example, answering how CAT bonds should be approached and integrated into a portfolio from a retail investor’s perspective. Ideally, this research should be accompanied by insights into alternative investment classes that tend to perform best at times when CAT bonds generally suffer. CAT bonds are, compared to many alternative investments, universally unexplored, especially for non-institutional investors and any research that investigates the market's potential for good or harm should be embraced and welcomed.

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Appendix

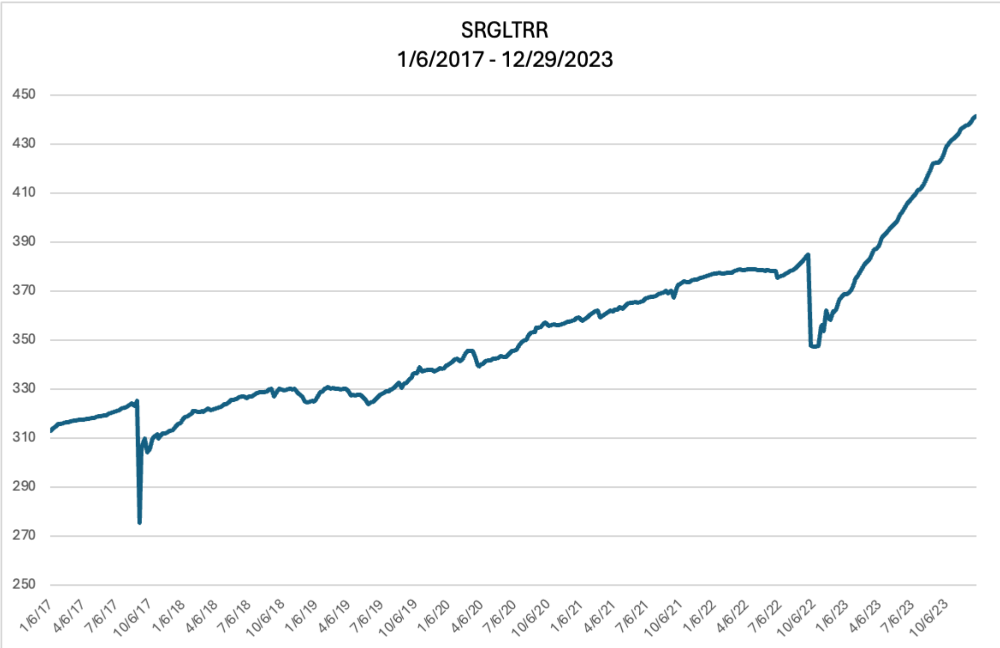

Figure A1 Swiss Re Global Cat Bond Performance Index (1/6/2017 - 12/29/2023)
Source Bloomberg

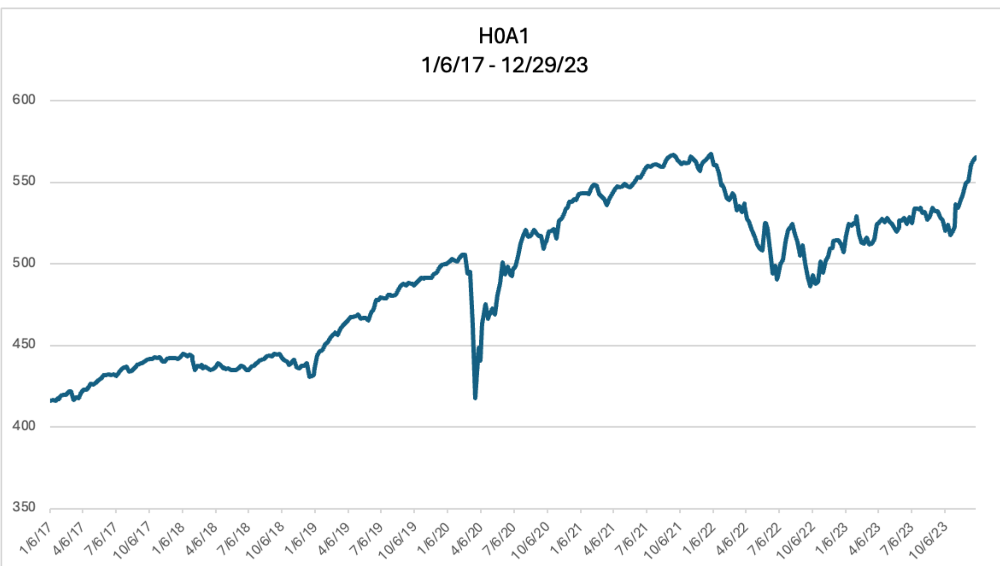

Figure A2 ICE BofA BB U.S. High Yield Total Return Index (1/6/2017 - 12/29/2023)
Source S&P Capital IQ

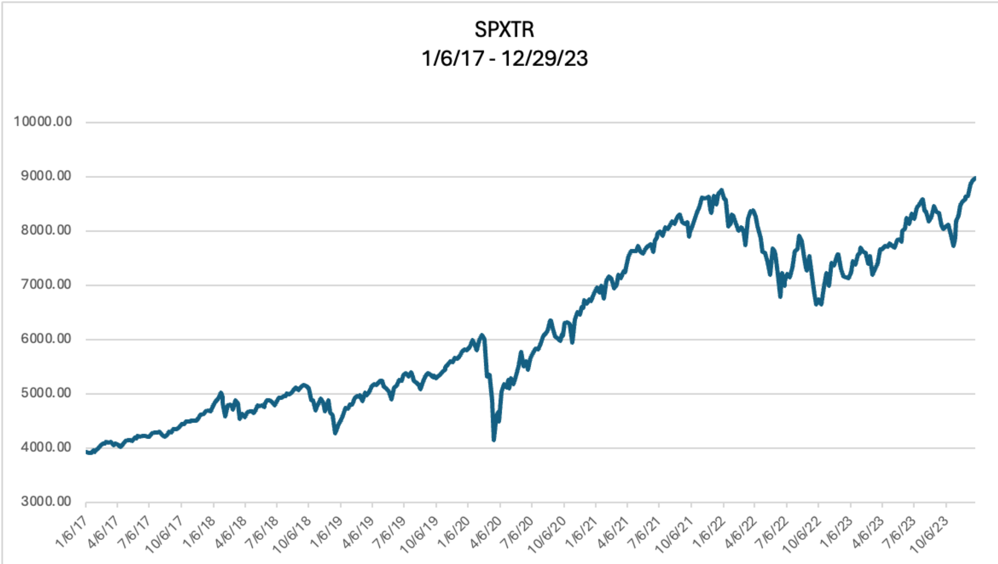

Figure A3 S&P 500 Total Return Index (1/6/2017 - 12/29/2023)
Source S&P Capital IQ

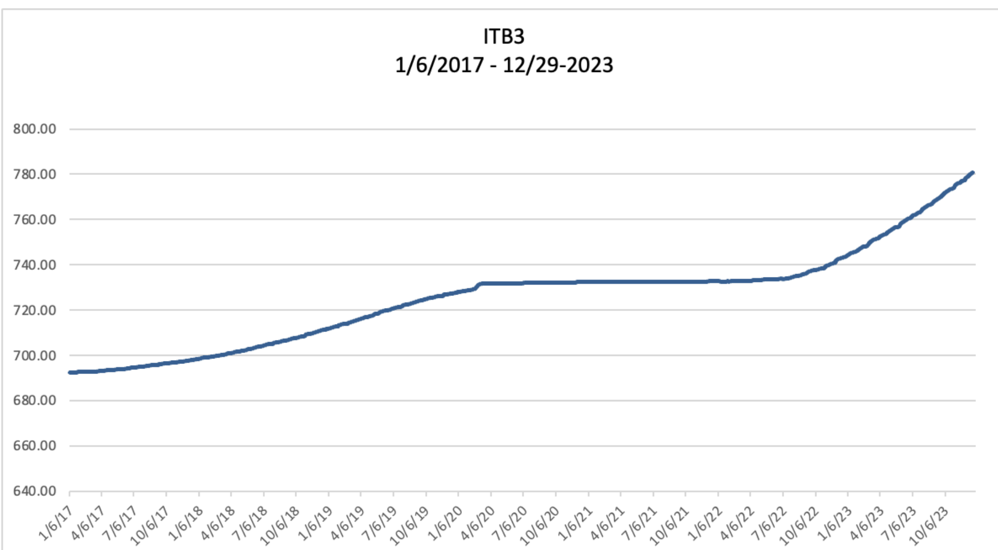

Figure A4 ICE U.S. Treasury Bill 3-Month Index (1/6/2017 - 12/29/23)
Source S&P Capital IQ

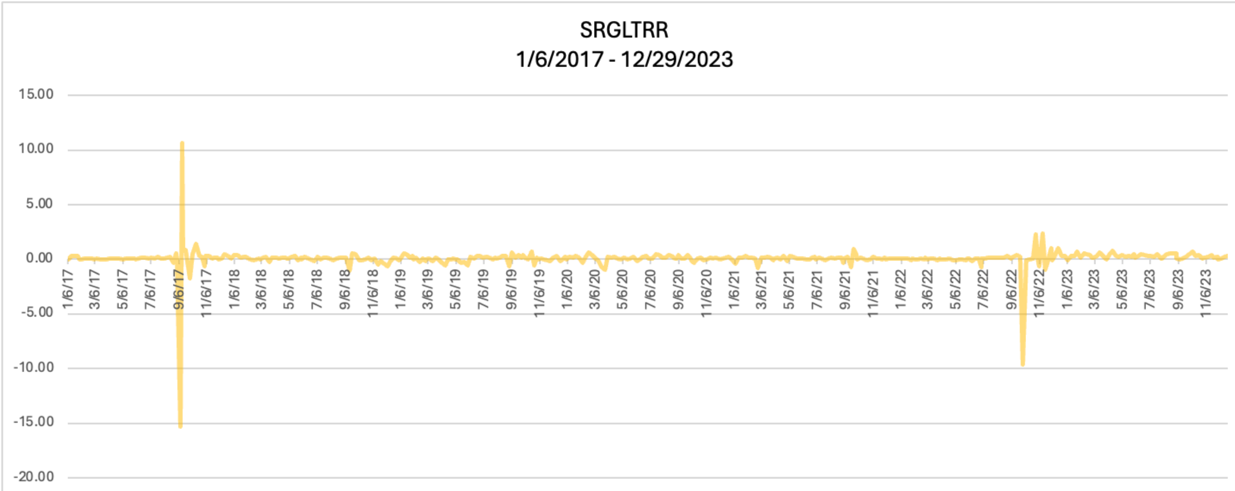

Figure A5 Weekly percentage returns of the Swiss Re Global Cat Bond Performance Index (1/6/2017 - 12/29/23)
Source Bloomberg

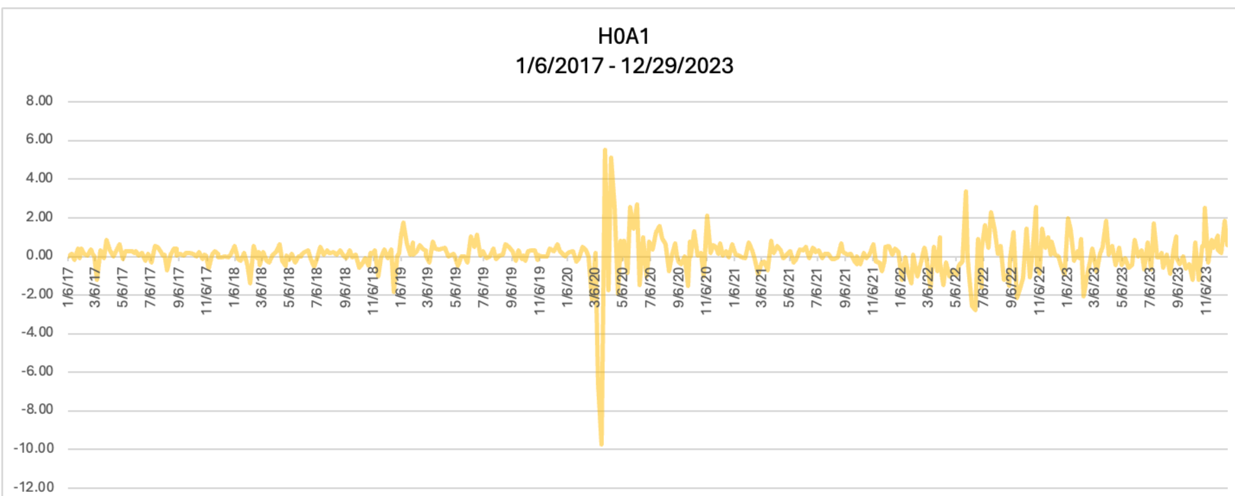

Figure A6 Weekly percentage returns of the ICE BofA BB U.S. High Yield Total Return Index (1/6/2017 - 12/29/23)
Source S&P Capital IQ

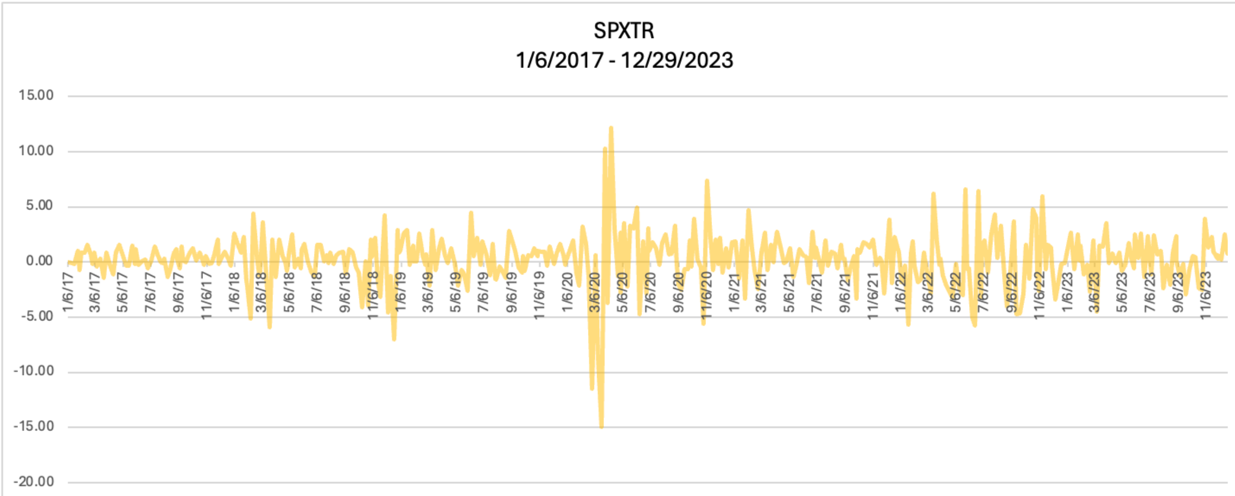

Figure A7 Weekly percentage returns of the S&P 500 Total Return Index (1/6/2017 - 12/29/23)
Source S&P Capital IQ

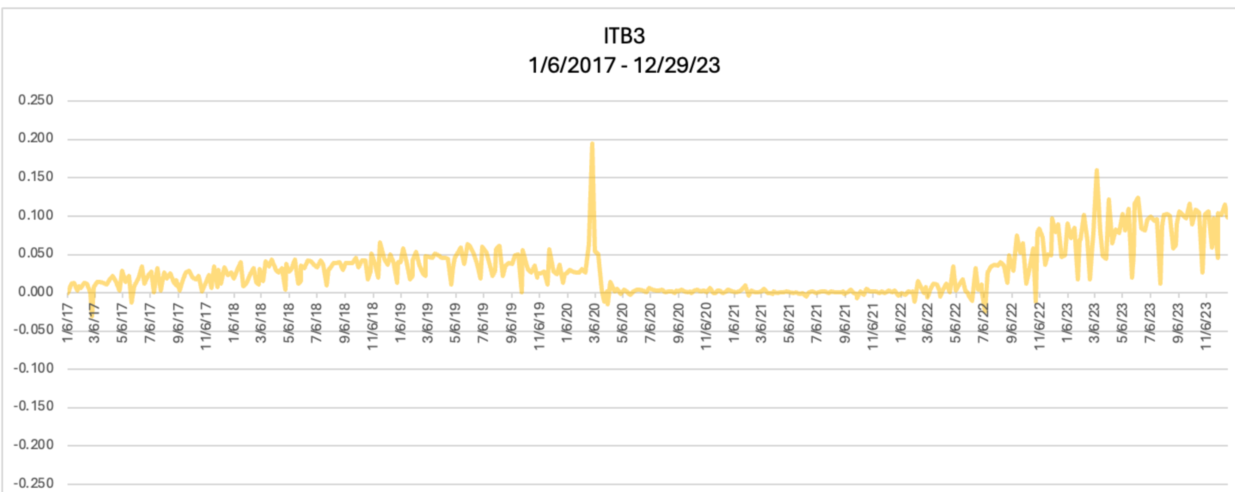

Figure A8 Weekly percentage returns of the ICE U.S. Treasury Bill 3-Month Index (1/6/2017 - 12/29/23)
Source S&P Capital IQ