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ABSTRACT

Do catastrophe bonds increase or decrease the exposure and contribution to systemic risk of issuing insurance companies? And if such issues influence systemic stability, what design features of the bond and characteristics of issuing insurer cause catastrophe bond issues to destabilize the financial sector? Contrary to current conjectures of insurance regulators, we find that the contribution of ceding insurers to systemic risk actually decreases significantly after the issue of a catastrophe bond. We empirically confirm that a higher pre-issue leverage, a higher firm valuation and previous cat bond issues all exert a decreasing effect on the issuer's systemic risk contribution.

Keywords: Cat Bonds, Insurance Industry, Systemic Risk.

JEL Classification: G22, G01, G34.

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"The potential for systemic risk within the insurance sector needs to be considered where insurers [...] enter into non-traditional insurance or non-insurance activities."

Peter Braumüller, Chairman, IAIS Executive Committee, May 31, 2012

1 Introduction

Does the issue of a catastrophe (cat) bond increase or decrease the exposure and contribution of the issuing insurer to the overall systemic risk of the financial sector? And if so, what characteristics of the issuer and the issued cat bond drive these changes in the insurer's systemic relevance? Since the financial crisis of 2007-2009, the potential of the insurance sector to destabilize the whole financial system has been discussed controversely.[1] On the one hand, both the fact that insurers are not vulnerable to bank runs of depositors and creditors and the hierarchical interconnectedness of insurers contradict the notion of systemic risks originating in the insurance sector.[2] On the other hand, for the most part due to the role American International Group (AIG) played during the crisis, regulators and economists now seem to agree on the potential of insurers becoming systemically relevant in case they engage too heavily in non-traditional or non-insurance activities (see, e.g., Cummins and Weiss, 2010, 2013; International Association of Insurance Supervisors, 2012; Weiß and Mühlnickel, 2013). One example for such non-traditional activities are cat bonds which are specifically designed to transfer the risk of large catastrophe losses to capital market investors. Yet while the risk-reducing effect on individual insurers (see Hagendorff et al., 2011) are undisputed, the effects of cat bond issues on the issuing insurers' systemic relevance due to an increased interconnectedness of investors are still unexplored.

In this paper, we analyze a sample of 176 cat bond issues and show that contrary to current conjectures of regulators, insurers decrease their contribution to systemic risk through issuing cat bonds. This effect is economically large as the average cat bond issuer decreases its contribution (measured by the issuer's ΔCoVaR, see Adrian and Brunnermeier, 2010) by 3.2%. At the same

[1] For discussions of the impact of the financial crisis on the insurance industry and its consequences, see Bell and Keller (2009) and Eling and Schmeiser (2010).

[2] For example, Chen et al. (2012) and Cummins and Weiss (2013) argue that insurers were victims, rather than contributors during the recent financial crisis.

time, the issuers' exposure to systemic tail events (measured by the issuer's Marginal Expected Shortfall, MES, see Acharya et al., 2010) is not significantly affected by the issue of a cat bond. After carefully testing the robustness of our key results by controlling for changes in the systemic relevance of non-issuing insurers, we address the question which characteristics of the issuing insurers and the issued cat bonds drive these changes in systemic risk. We find that a higher pre-issue leverage, a higher firm valuation and previous cat bond issues all exert a decreasing effect on the issuer's systemic risk contribution.

Catastrophe risk is of major concern to both insurers and reinsurers and over the past decade, cat bonds have evolved into the instrument of choice for hedging catastrophe risk outside the traditional reinsurance business. In the first analyses on cat bonds, several authors questioned the benefits of using cat bonds to hedge underwriting losses (see Froot, 2001; Lakdawalla and Zanjani, 2012; Froot and O'Connell, 2013). For example, early empirical evidence on alternative risk transfer instruments found that insurers purchased only little cat reinsurance due to supply restrictions and market power exerted by traditional reinsurers (see Froot, 2001). In line with the theoretical analysis of Lakdawalla and Zanjani (2012), Hagendorff et al. (2013) present empirical evidence that cat bond issues do not lead to significant abnormal returns for shareholders in issuing firms. They conclude that market participants prefer cat bonds over other alternatives due to the former having low costs, but not for their effectiveness for hedging catastrophe risks. Despite these findings, the overall issue volume of cat bonds has grown steadily over the last decade.[3] One reason for the increasing popularity of cat bonds could be their risk-reducing effect on an insurer's default probability. In the first empirical study on the risk implications of cat bonds, Hagendorff et al. (2011) show that cat bonds are effective in hedging underwriting risks and consequently in decreasing the ceding insurer's default risk. The effects of issuing cat bonds on both the issuing insurer's systemic risk exposure and contribution, however, remain relatively unexplored in both the theoretical and empirical literature.

On the one hand, several studies argue that severe natural catastrophes could lead to de-

[3] See, e.g., AON Capital Markets (2010) and Carpenter (2012) for recent analyses of the global cat bond market.

faults of insurers and reinsurers and consequently to the instability of the insurance sector (see Cummins et al., 2002; Harrington and Niehaus, 2003; Cummins and Trainar, 2009). If the fragility of the insurance sector spills over to the rest of the financial system (e.g., due to the interconnectedness of some systemically important insurers, see Cummins and Weiss, 2010; Chen et al., 2012; Billio et al., 2012), natural catastrophes could then destabilize the whole financial sector. In this setting, issuing a cat bond should ceteris paribus decrease an insurer's exposure to systemic risk as the issuer is able to transfer and diversify its catastrophe underwriting risk. In addition, the issuer's contribution to systemic risk should also decrease if the systemic benefits of reducing the issuer's default probability exceed the adverse effect of capital market investors assuming catastrophe risk outside the insurance business. On the other hand, insurance regulators have become increasingly aware of the potential of insurance-linked securities (ILS) to destabilize the insurance sector and the financial system as a whole. Most prominently, the International Association of Insurance Supervisors (IAIS) argues in their "Insurance and Financial Stability" report that although the ILS market simply serves as a distribution mechanism for underwriting risks, the securitization of insurance risks based on poor underwriting may potentially create systemic risks (see International Association of Insurance Supervisors, 2011). Also, the beneficial risk-reducing effect of a cat bond on the issuing insurer could be outweighed by the detrimental effect of increasing system-wide catastrophe risk exposure. Consequently, the theoretical prediction on the possible effect of cat bond issues on systemic risk is ambiguous.

Our results show that insurers decrease their contribution to systemic risk via issuing a cat bond. Contrary to claims by regulators (see International Association of Insurance Supervisors, 2011) and in line with the results found by Hagendorff et al. (2011), cat bond issues are associated with a risk-reducing effect on issuers. The issuer's exposure to externalities spilling over from the financial sector, however, is not significantly affected by a cat bond issue. This result is intuitive and in line with our expectation. Raising capital and additionally insuring against catastrophe risk does not significantly affect the issuing insurer's susceptibility to turmoil in the financial sector. In our regression analyses we find that leverage and a high firm valuation both exert a disciplining influence on the issuer in turn decreasing its contribution to systemic risk. In addition to this, frequent cat bond issues also appear to have a stabilizing effect on the financial sector.

2 Data and variables

2.1 Sample selection

We start by collecting data on all cat bonds listed on *ARTEMIS* (www.artemis.bm) that were issued between December 1, 1996 and April 1, 2013.[4] In total, our initial sample consists of 284 cat bonds. We intend to use the insured risk of the cat bonds as an explanatory variable and therefore omit an issue if its underlying is either not sufficiently specified (e.g., “all”, “life reinsurance”) or occurs only once in our sample (“temperature”, “casualty losses”, “event cancellation”, “credit reinsurance”, “lottery winnings”). This is the case for 13 issues. For similar reasons, we lose seven issues because of multiple trigger types and four issues lacking information on the trigger type. Another four issues are excluded due to different maturities within their tranches. Since our investigation is concerned with the systemic relevance of insurers only, we omit from our sample six issues of non-insurance companies and two cat bonds with unknown cedents.

We check whether the issuer is a publicly listed company and require an insurer to have stock price data available from *Thomson Reuters Financial Datastream* to be included in our sample. Due to this requirement, we lose 66 issues. In addition, we retrieve financial accounting data used in our cross-sectional study from *Thomson Reuters Worldscope*. To control for known data errors in *Datastream*, we apply several screening procedures for the daily returns on the insurers’ stock prices that are commonly applied in the empirical literature (see Ince and Porter, 2006). First, we exclude from our sample days on which the stock price of a respective issuer drops at least once below a minimum price of US $ 1 to control for a bias induced by the practice in *Datastream* of rounding prices. Second, we check whether our sample includes monthly returns above 300%

[4] *ARTEMIS* is, e.g., also used in the study of Gürtler et al. (2012) on the effects of desasters and the financial crisis on the pricing of cat bonds.

that are reversed in the following month. If present, such returns are deleted from our sample to minimize differences between the *Center for Research in Security Prices (CRSP)* database and *Datastream*. None of the return series exhibit such data errors. Next, we exclude two issuing insurers from our sample due to having a stock with zero returns on all days in our sample period around the issue and announcement dates. Finally, we also exclude non-trading days from our final sample of stock prices.[5]

For the remaining 182 issues, we perform various cross-checks using data from *ARTEMIS, LexisNexis, Swiss Re Capital Markets, AON Capital Markets, Guy Carpenter, Cayman Islands Stock Exchange* (www.csx.com.ky) and the firms' websites for details on the cat bonds' issue and announcement dates. Following Hagendorff et al. (2013), we employ both the announcement and the issue dates in our event study, and in cases where the issue date precedes the announcement date, we employ the issue date as the announcement date. In six cases we were not able to find information on the issue date and therefore exclude these from our sample. Our final sample consists of 176 cat bond issues. For increased transparency, the effect of the various data filters we apply on the sample of cat bond issues is illustrated in Appendix I. In our final sample, Swiss Re issued 68 cat bonds during our sample period which makes them the most frequent issuer. Seven insurers are identified as frequent issuers in our sample. An overview of the distribution of issues by the insurers can be found in Appendix II.

In the following subsections, we define and discuss the different dependent and independent variables we use in our empirical study. All variables and data sources are defined in Appendix III.

2.2 Measures of Systemic Risk

As our main dependent variables, we employ three different measures of systemic risk. These measures have been extensively discussed in the recent literature (see, e.g., Benoit et al., 2013) and are also used by regulators for identifying globally systemically important financial institutions.

[5] Non-trading days are identified as those days on which the ten largest insurance companies (with respect to their market capitalization) in a respective country available in *Datastream* exhibit a stock return equal to zero.

The first measure we use in our study is the Marginal Expected Shortfall (MES) as proposed by Acharya et al. (2010). It is defined as the negative mean of the log returns on an individual issuer's stocks, conditional on the financial sector experiencing its worst 5% outcomes with positive values for MES indicating a larger exposure to adverse effects spilling over from the financial sector (and vice versa). In our estimations, we make use of the dynamic model specification of MES presented by Brownlees and Engle (2012), which allows for time varying volatility and correlations in the equity returns of individual financial institutions and the sector index.[6] We first compute daily dynamic MES estimates in the two periods with a length of 180 trading days before and after the event date of a cat bond issue. Next, the daily MES estimates are averaged in both periods around the issue event to yield a pre-issue and post-issue estimate of the issuer's *exposure* to systemic risk. The change in the MES around the cat bond issue is then used as a dependent variable in our cross-sectional regressions.

Next, we follow Adrian and Brunnermeier (2010) in their definition and estimation of the conditional ΔCoVaR to measure an insurer's *contribution* to systemic risk. In their study, Adrian and Brunnermeier (2010) define a financial institution's CoVaR as the Value-at-Risk (VaR) of the financial system conditional on institutions being under distress. An issuer's contribution to system risk is then measured as the difference between CoVaR conditional on the issuer being under distress and the CoVaR in the median state of the institution.[7]

The third measure we implement is the Systemic Risk Index (SRISK), defined by Acharya et al. (2012) and Brownlees and Engle (2012) that tries to measure the expected capital shortfall of an issuer in a crisis by incorporating the dynamic MES in a measure of the institution's debt. The

[6] To be precise, the joint behavior of the market and firm returns are modeled with the TARCH (see Rabemananjara and Zakoïan, 1993) and DCC (see Engle, 2002) specifications.

[7] Following Adrian and Brunnermeier (2010), we employ the change in the three-month Treasury bill rate, the difference between the ten-year Treasury Bond and the three-month Treasury bill rate, the change in the credit spread between BAA-rated bonds and the Treasury bill rate, the return on the Case-Shiller Home Price Index, and implied equity market volatility from VIX as state variables in the estimation of each issuer's conditional ΔCoVaR around cat bond issues.

SRISK estimate for issuer i at time t is given by

$$SRISK_{i,t} = k\,(Debt_{i,t}) - (1-k)\,(1 - LRMES_{i,t})\,Equity_{i,t} \quad (1)$$

where k is a regulatory capital ratio (set to 8%), $Debt_{i,t}$ is the issuer's book value of debt, $LRMES_{i,t}$ is the long run Marginal Expected Shortfall defined as $1 - \exp(-18 \cdot dynMES)$, $dynMES$ is the dynamically estimated MES and $Equity_{i,t}$ is the issuer's market value of equity. Similar to the MES and ΔCoVaR, we compute an issuer's SRISK for the periods with a length of 180 trading days before and after the event date of an issue and then employ the differences in our regressions.

2.3 Insurer Characteristics

For our first set of independent variables, we choose several indicators of systemic relevance suggested by the IAIS for detecting systemically important insurers.[8] An insurer's size is expected to influence significantly its contribution and exposure to systemic risk. As a proxy of an insurer's size, we use the logarithm of its' total assets. On the one hand, we expect the coefficient of total assets in our regression to be positively correlated with systemic risk exposure and contribution, since a larger company is less likely to suffer from cumulative losses due to its broader range of different risks insured. On the other hand, an insurance company could become more systemically relevant by being too-interconnected-to-fail (see, e.g., Acharya et al., 2009). As an alternative proxy for an insurer's size, we also employ the variable Net revenues, which is the log value of the issuer's total operating revenues.

Next, we include in our regressions the variable Non-policyholder liabilities. It is defined as the difference of the total of balance sheet liabilities and total insurance reserves (including benefit and loss reserves, unearned premiums, policy and contract claims and other reserves) and is therefore used to capture an insurer's activity outside the classical insurance business. Furthermore, we suspect an increase in the contribution of an issuer to systemic risk, if the issuer is more intertwined

[8] Note that not all indicators proposed by the IAIS can be used in our study as several of their variables are based on confidential firm data that are unavailable to us.

with global financial markets. To proxy for this, we define an issuer's Investment activity as the absolute value of investment income divided by the sum of the absolute values of investment income and earned premiums. This ratio proxies the degree with which the insurer derives its income from investing in assets rather than earning premiums from underwriting. In addition, we include the variable Investment success which is defined as an insurer's investment income divided by its' net revenues.

We also employ several other variables concerning different insurer characteristics. By following Acharya et al. (2010) and Fahlenbrach et al. (2012), we obtain an approximation to an issuer's leverage by taking the ratio of the quasi-market value of assets and the market value of equity. The quasi-market value of assets is simply given by the book value of assets plus the market value of equity minus the book value of equity. The sign of the coefficient of leverage in our regression is expected to be unrestricted. Vallascas and Hagendorff (2011) argue that managers of companies with high leverage could feel pressured by investors to provide enough liquid assets to cover the payment of interests. As a consequence, a higher leverage might decrease an insurer's total risk. At the same time, high leverage is a factor that could force managers into having an affinity for excessively taking on more risk to increase a firm's profitability. Support for this view is found by Acharya et al. (2010), Fahlenbrach et al. (2012) and Hovakimian et al. (2012) who find empirical evidence for better firm performance and a smaller contribution to systemic risk by banks with low leverage during the crisis.

In addition, we take an insurer's market-to-book ratio, defined as the book value of common equity divided by the market value of common equity, as an independent variable. Since an overvaluation of an insurance company might set up for high growth expectations on the part of investors, we suspect a negative correlation between the market-to-book ratio and systemic risk. As before, overstated growth expectations could also lead to more risk-taking by managers (see, e.g., Milidonis and Stathopoulos, 2011).

The next insurer-specific variable we consider is Debt maturity, which is defined as the ratio of total long-term debt and total debt. Since previous studies have found that a financial institution's use of short-term funding led to higher exposure to systemic risk during the financial crisis (see, e.g., Brunnermeier and Pedersen, 2009), we expect a higher value of Debt maturity to decrease an insurer's exposure to systemic risk.[9]

As pointed out in De Haan and Kakes (2007), a higher profitability of an insurer is related to decreases in its contribution to systemic risk. This is because insurance companies with higher profits also have higher solvency margins and a lower risk of insolvency. To capture an insurer's profitability, we use the variable Return on assets at the end of the year before the cat bond was issued. To further check whether an issuer's performance before the announcement of a cat bond issue has an effect on the issuer's systemic risk, we define the variable Performance as the buy-and-hold returns (in %) of an insurer for the period from 252 to 20 days before the announcement date. We would expect a good performance to decrease an insurer's exposure and contribution to systemic risk (see also Fahlenbrach et al., 2012). As another proxy for an issuer's overall performance, we also employ its loss ratio calculated by adding claim and loss expenses and long term insurance reserves and then dividing the sum by premiums earned. We suspect a higher contribution to systemic risk by issuers that have a higher loss ratio and thus a better quality of their insurance portfolio.

Inspired by Diamond and Rajan (2009) and Aebi et al. (2012), who find that poor governance influenced the severity of losses that banks suffered during the financial crisis, we include the two variables Board size and Board independence in our cross-sectional analyses. We define Board size as the natural logarithm of the number of directors on an insurer's board. Yermack (1996) shows that larger boards tend to destroy firm value and possibly capital buffers, which is why we suspect a positive relation between Board size and systemic risk. Board independence is the percentage of independent outside directors on the board of directors. As a proxy for independence on the insurer's board of directors, we expect a decreasing impact on the systemic risk of an insurer, since outside directors should have more concerns about a financial sector's risk as a whole.

We also include information on the accounting standards used by an issuer as a control variable.

[9] Note that we use long-term debt instead of short-term debt to calculate our variable Debt maturity

Therefore, we take the variable IFRS which takes on the value of integers from one to 23 where one means that the insurer reports according to local standards and 23 that they use the guidelines of IFRS. The numbers in between correspond to different variations of national and international reporting standards (details on the coding of this variable can be found in the documentation of the *Worldscope* database).

The final two idiosyncratic variables take into account how often a single insurer has issued a catastrophe bond. A bigger number of issues might lead to a higher contribution and exposure to systemic risk, since the insurer is then more intertwined with the global financial market. We therefore follow Hagendorff et al. (2013) and use the number of previous cat bond issues undertaken by the issuer as an independent variable, as well as the dummy variable Frequent issuer, which equals one, if the insurer has issued five or more cat bonds during the observation period and zero otherwise.

2.4 Catastrophe Bond Characteristics

Our second set of independent variables addresses the design features of the issued catastrophe bonds. First, we employ the variable Issue size defined as the total value of an issued cat bond divided by the ceding insurer's book value of equity. In our regressions, we expect the coefficient of Issue size to be unrestricted. On the one hand, an insurer becomes more exposed to systemic risk by taking on more debt through issuing a cat bond. On the other hand, the primary motivation for an insurer to issue a cat bond is its intention to insure against severe losses due to extreme events. Issue size could therefore also be negatively correlated with systemic risk. One could also argue that a longer maturity of a cat bond increases the exposure and contribution of the issuer to systemic risk. Therefore, we use the maturity of the cat bond expressed in month in our regressions as a further independent variable.

A cat bond can be characterized by a wide range of trigger types, such as index, parametric and indemnity triggers. A full protection against occurring losses caused by catastrophes is given by the latter trigger type. We intend to answer the question whether the type of the trigger has a significant impact on the effect of cat bond issues on systemic risk. Consequently, we use the dummy variable Indemnity, which equals one if the cat bond uses an indemnity-based trigger and zero otherwise. As mentioned in Hagendorff et al. (2013), indemnity-based triggers suffer from higher transaction costs and moral hazard problems, since an issuer might be better informed about the covered risk. Due to this, we predict the Indemnity variable to be positively correlated with the changes in the issuers' systemic relevance.

Another design feature of a cat bond that might drive the issuer's systemic risk exposure and contribution around the issue dates is its rating given by Standard and Poor's and Moody's. First, we follow Hagendorff et al. (2011, 2013) and convert a cat bond's rating into a numerical value by assigning the number one to issues rated as AAA by S&P (or Aaa by Moody's), two to issues rated as AA+ (Aa1), and so forth. Since an issue is often divided into several tranches with different ratings, we consolidate the ratings of the different tranches by calculating their weighted average (weighted by amount of US $ in the tranches). A higher value of this variable Rating (a lower rating by S&P) could indicate a greater probability that the cat bond trigger gets activated. We therefore suspect Rating to have an increasing effect on the issuer's contribution to systemic risk. Finally, we employ in our regressions the control variable Secured risk, which is equal to one if the cat bond covers mortality-related risks or medical benefit claims and zero otherwise.

2.5 Country Characteristics

To control for differences in the ceding insurer's countries, we use several macroeconomic and country-level control variables. First, we include in our regressions the variable Inflation, defined as the natural logarithm of the annual change in inflation rate. Shiu (2004) finds evidence for a negative relation between inflation and insurer and bank performance. We therefore expect an increase in the contribution to systemic risk, a result which is also found by Bernoth and Pick (2011). Additionally, we use the growth rate of the GDP as a standard macroeconomic control variable. To proxy for a country's shareholder protection rights, we use the Anti-Director Rights Index introduced by La Porta et al. (1999) and revised by Djankov et al. (2008) and Spamann (2010).

Another country-specific variable we employ is the Herfindahl-Hirschmann index (HHI) to measure for the competition in a country's insurance sector. It is defined as the sum of the squared market shares of all insurers based in a country. Uhde and Heimeshoff (2009) find evidence for a negative effect of the HHI on systemic risk, whereas Beck et al. (2006) conclude the contrary. Therefore, we have no prediction for the influence of the HHI on systemic risk in our regressions.

For each country we also employ the Political Stability index from the Worldbank's *World Development Indicator* database, which measures the perceptions of the likelihood that unconstitutional or violent actions destabilize or overthrow the government. A higher value indicates a more stable political governance. Finally, we include an index for the local reinsurance market in a specific country, which could be a driving factor for an insurer's need for alternative risk-securitization. For each issue we take the Reinsurance prices from the ceding insurer's country in the year the cat bond was issued. Data on reinsurance prices are obtained from *Guy Carpenter*.

2.6 Descriptive Statistics

Table I shows descriptive statistics for our independent variables and the estimated systemic risk measures. As dependent variables in our regressions, we employ the changes in SRISK, MES and ΔCoVaR around cat bond issue dates.

- Insert Table I here -

The statistics given in Table I show that cat bond issues do not coincide with an economically or statistically significant change in the average issuer's SRISK. In line with our expectation, however, the issuers' exposure to systemic risk decreases considerably after the issue of a cat bond. As evidenced by the decrease of -1.04% in the issuers' MES, issuing insurers appear to decrease their vulnerability to externalities spilling over from the financial sector. Similarly, we can see from the mean change in ΔCoVaR that the contribution of the issuing insurers to systemic risk also decreases. Mean ΔCoVaR increases by 3.44%. This first analysis thus first hints at the possibility that cat bond issues could have a stabilizing rather than a destabilizing effect on the financial sector.

Concerning the insurer characteristics, several aspects deserve to be highlighted. The total assets of the insurers in our sample are between 0.90 and 1,350.21 billion US $ and the average and median are 207.82 and 143.94 billion US $, respectively. The mean return on assets of issuers in our sample is positive. Furthermore, issuers in our sample also have positive mean values for our variables Investment success, Investment activity and Performance. The mean issuer in our sample also has approximately 29% non-policyholder liabilities and a mean loss ratio of 85%.

The distribution of the cat bond issues in our sample over time is depicted in Figure 1.

- Insert Figure 1 here -

We can see that from 1997 to 2002, only few cat bonds were issued each year, whereas in 2003 and the following years we find a significant surge in the number of annual issues by insurers. In 2006, a total of 27 Cat bonds in our sample were issued, which is the highest number of yearly issues. This is followed up by a dramatic decrease in 2008 and an upward trend of the issuing frequency. Concerning the size of the issues, the plot in Figure 1 shows that the value size of the issues follows a similar trend. The average volume of catastrophe bond issues is 153.17 million US $ per year, with a range from six to 550.25 million US $. The percentage of the issues that used indemnity-based triggers is 8% and we can also see that 6% of the observations secured mortality-related risks or medical benefit claims. On average, the maturity of a cat bond was around three years and one month with the shortest period being twelve months and the longest maturity being almost six years. Table I also reveals that the average rating assigned to a cat bond was BB- (S&P).

3 Empirical study

In this section, we present the results of the systemic risk estimates of cat bond issuing insurance companies and matched non-issuing insurance companies and then turn to the cross-sectional analysis of our three systemic risk measures around cat bond issues.

3.1 Systemic Risk Effects

Results on the cat bond issue-related changes in the three measures of systemic risk are presented in Table II.

- Insert Table II here -

For our full-sample analysis, we first estimate cat bond related changes in the issuers' SRISK.[10] We find only little evidence for a statistically significant increase in SRISK. More precisely, issuers' exposure to global systemic risk measured by SRISK increases though the change in SRISK is neither statistically nor economically significant. This first result is rather intriguing as the (automatic) increase in the issuer's contribution to systemic risk due to the increase in total debt appears to be offset by the stabilizing effect of the cat bond issue on the issuer's equity (i.e., the dynamic MES).

The results of our second systemic risk measure (dynamic MES) show that cat bond issuers statistically significantly decrease their exposure to systemic risk by -0.9 %. This effect is also economically significant as the issuers' equity returns in times of market crisis increase by almost one per cent. Cat bonds are used as an effective hedging instrument of issuers' underwriting risk. Consequently, and in line with the results of Hagendorff et al. (2011) on the default risk implications of cat bonds, we find issuers to decrease their susceptibility to spillover effects from the financial sector.

The results for the ΔCoVaR estimates in Table II underline our previous finding that as a consequence of the cat bond issue, the issuing insurers decrease their contribution to overall systemic risk. Although this result is not statistically significant, the effect is nevertheless economically large. The ΔCoVaR of the average issuer increases by 3.2% around the cat bond issue. A natural explanation for this finding is that the decrease in the issuing insurers' default probability due to the hedging of catastrophe risks has a significant stabilizing effect on the financial sector. In

[10] We also include several cat bond issues in this analysis for which we do not have data on all accounting variables. Consequently, the sample size in this analysis is slightly larger than in the previous analysis documented in Table I.

contrast, this stabilizing effect does not seem to be outweighed by the destabilizing side-effect of capital market investors assuming catastrophe risks and thus increasing interconnectedness.

It could be argued that the changes we find in the three systemic risk measures are not due to the insurers issuing cat bonds but to some unobserved sector-wide trend that affects all insurers. To investigate the question whether the contributon or exposure to systemic risk is different for issuing and non-issuing insurance companies, we employ a matching approach using propensity scores and compare the systemic risk effects for issuers and matching non-issuers. We aim to match a non-issuing insurer to a similar cat bond issuing insurer of similar size. To be precise, we follow Drucker and Puri (2005), Bartram et al. (2011) and Bartram et al. (2012) and use propensity score technique to compare insurance companies along one dimension, i.e., the insurer's total assets.[11] We employ the size of the insurer in our matching of issuers and non-issuers as it has been frequently stated by both the International Association of Insurance Supervisors (2012) and found by empirical studies (see, e.g., Weiß and Mühlnickel, 2013) that insurer size is the key driver of systemic risk in insurance. The matching is done by first estimating a logit-regression with the dependent variable differentiating between issuing and non-issuing insurers and our matching variable total assets. Next, we follow the "nearest-neighbor" technique which minimizes the estimated propensity scores of our cat bond issuing insurers and corresponding non-issuers. For each cat bond issue, we develop a matching conditional that the non-issuing insurer has his headquarters in the same country as the issuer and stock market and balance sheet data readily available from *Thomson Reuters*.

Table III presents the results of our systemic risk measures for cat bond issuing and non-issuing insurance companies.

- Insert Table III here -

To ensure a good matching quality, we only consider matched insurer pairs with statistically insignificant differences between the issuing and the non-issuing insurers' propensity scores. Con-

[11] We also perform a matching of issuers and non-issuers along two dimensions using the insurers' size and leverage. This analysis is not successful due to the bad quality of the resulting matching.

sequently, the total number of cat bond issues we analyze in this part of our investigation is reduced to 110, 119 and 121 issues, respectively.

The results for our first systemic risk measure (SRISK) show that cat bond issuers decrease their exposure to systemic risk, although this effect is not statistically significant. Conversely, SRISK increases slightly for the matching non-issuing insurers. However, the difference in the issue-related change in SRISK between issuers and matching non-issuers is neither statistically nor economically significant.

Next, we investigate whether the reduction in the issuers' exposure to systemic risk is genuinely caused by the issue of a cat bond or rather by sector-wide effects. The results for the dynamic MES show that issuing insurers decrease their exposure to systemic risk by 1.1% although this economically significant change is not statistically significant. However, non-issuing insurance companies also experience an economically significant decrease in their exposure to systemic risk (-1.6%). The difference between the changes in the MES of issuers and non-issuers, nevertheless, is not significant. We thus find no empirical evidence that supports the hypothesis that cat bond issues significantly affect the issuer's exposure to systemic crises.

Most interestingly, our findings for the ΔCoVaR of issuers and non-issuers show that the contribution of non-issuers to systemic risk around cat bond issues does not significantly change. At the same time, the contribution of issuing insurers to systemic risk is economically significantly reduced by almost 4.3%. Consequently, our results strongly support the hypothesis that cat bond issues add to the stability rather than the fragility of the financial sector.

3.2 Cross-Sectional Regressions of Systemic Risk

We now turn to the results of our cross-sectional analysis to determine which factors can explain both the cat bond issuers' contribution as well as exposure to systemic tail events. Therefore, we estimate several regression models using the changes between the cat bond issuers' pre-announcement and post-issue SRISK, dynamic MES and ΔCoVaR as our main dependent variables.

As our dependent variables stem from a first-stage estimation, our regression-models could suffer both from heteroskedasticity as well as inconsistent standard error estimates. We therefore estimate our regressions using Ordinary Least Squares (OLS) with Newey-West standard errors to control for heteroskedasticity and possible autocorrelation. We use three sets of cross-sectional OLS regressions to answer the question which insurer-specific, cat bond-specific or country-specific variables have an influence on the issue-related changes in systemic risk. To mitigate the problem that our systemic risk measures and some regressors could be determined simultaneously, we use pre-announcement explanatory variables lagged by one quarter. Additionally, we estimate a set of different regression-model specifications controlling for the insurers' board structure, investment activity and loss ratio to assess our regressions' sensitivity to the inclusion of these control variables. Correlations between our regressors are presented in Table IV.

- Insert Table IV here -

Table IV shows that there exist some variable pairs which could cause multicollinearity problems in our regressions. These highly correlated variables are not used simulataneously in the regressions we describe in the following. Table V reports the results of the regressions on Cat bond issuer-related changes in SRISK, dynamic MES and ΔCoVaR.

- Insert Table V here -

Model (1) constitutes our baseline regression in which we use our full-sample of issuing insurance companies. We find no evidence pointing at a significant relation between the issuers' size and their exposure to systemic risk. More precisely, insurer size which is measured by the logarithm of the insurers' total assets has a positive but not statistically significant effect on the cat bond issuers' changes in SRISK. The changes in the exposure to systemic risk are thus not determined by the pre-issue level of insurer size. Additionally, the pre-announcement market-to-book value enters regression (1) with a statistically significant negative coefficient. Insurers with a higher market-to-book value and therefore with a higher charter value could provide managers incentives to increase their capital ratios and consequently limit their risk-taking. This effect can decrease the insurers' default probability thus decreasing the issuers' exposure to systemic risk. This effect is also economically significant with a one standard deviation increase in the market-to-book value causing a decrease of 140 million US \$ (1.838 × 0.763) in SRISK. Additionally, it could be argued that differences in issuers' accounting standards could have a significant impact on any of our systemic risk measures. The variable IFRS enters regression (1) both with a statistically as well as an economically significant negative coefficient. We find consistent evidence that issuers reporting their results following IFRS decrease their SRISK.

Turning to the cat bond characteristics, most of our variables enter regression (1) with a statistically significant coefficient. Issue size, which is defined as the value of an issued cat bond scaled by the ceding insurers' book value of equity, enters our regression with a significant positive coefficient. On the one hand, the insurers' leverage increases due to taking on more debt through the cat bond issue which has a significant effect on SRISK which is computed from the insurers' total debt. On the other hand, a larger issue does not necessarily provide issuers with more diversification benefits, which could have a positive impact on SRISK. This result is also economically significant as a one standard deviation increase in the issue size results in a 224 million US \$ (0.019 × 118.361) increase in SRISK. Moreover, the dummy variable Indemnity, which equals one if the cat bond uses an indemnity-based trigger and zero otherwise, has a statistically significant positive effect on SRISK. This result could be explained with the moral hazard problem caused by better informed issuers exploiting unsuspecting investors. More precisely, issuers could be inclined to issue high-risk bonds to investors thus increasing systemic risk in the whole financial sector. Additionally, the variable secured risk is significantly negatively related to SRISK. Secured risk is a dummy variable that takes on the value one if the cat bond securitizes mortality-related risks or medical benefit claims and zero otherwise. This means that non-life insurance cat-bonds trigger seem to affect SRISK differently than cat bonds used for hedging underwriting losses in life insurance. This effect is also economically significant. Finally, our country-specific variables show that a higher GDP growth and a higher sector concentration have a negative impact on SRISK.

In regression (2), we control for the sensitivity of our results. Due to a possible bias in our estimates due to multicollinearity between total assets and both leverage as well as investment activity, we exclude total assets and reestimate our previous regression including also the insurers' loss ratio. Most importantly, issuer leverage enters regression (2) with a statistically significant positive coefficient. However, one could argue that the positive correlation between SRISK and leverage is an automatic consequence of the fact that issuers raise their leverage by means of a cat bond issue (and thus their total debt included in SRISK). The results for our cat bond characteristics as well as country characteristics remain qualitatively unchanged.

In regression (3), we consider the issuers' board structure in our estimations by including both Board size as well as Board independence as additional variables. The significance of the coefficient on the issuers' leverage remains unchanged. As an additional insurer characteristic variable, investment activity enters our regression with a significant negative coefficient. The relation between investment activity, which is a proxy for the insurers' interconnectedness with the global financial markets, and SRISK indicates that issuers' deriving their income from investing in assets rather than in earning premiums from underwritings decrease their exposure to systemic risk. This result may seem counterintuitive at first. However, insurers engaging more in investment activities could increase their profitability thus decreasing SRISK through diversification benefits. An unreported regression, using investment success instead of investment activity, confirms our results. In line with our previous findings, the variable Return on assets is also statistically significant implying that more profitable issuers can decrease their SRISK due to the cat bond issue. This relation is also economically significant with a one standard deviation increase in Return on assets increasing the change in SRISK by 199 million US \$ (1.486×1.34). Additionally, the insurers' performance has a statistically significant negative impact on SRISK. This result implies that a better performance measured by the pre-announcement buy-and-hold returns, results in a decrease in SRISK. An increase in the lagged buy-and-hold returns by a one standard deviation leads to a decrease in SRISK of 258 million US \$ (10.718×0.241). Issuers that performed better in the pre cat bond issue period thus reduce their exposure to systemic risk. The variable IFRS is no longer statistically significant but remains economically significant.

The coefficients of the board structure are not statistically but economically significant. On the one hand, board size has a positive impact on SRISK, due to the fact that larger boards tend to destroy firm value and possible capital buffers thus leading to an increase in SRISK. On the other hand, higher board independence has a negative impact on SRISK, since outside directors might have more concerns about a financial sectors' risk as a whole. Finally, the high adjusted R-squared values for our regressions using SRISK as our dependent variable show that a large portion of issue-related changes in issuers' SRISK can be explained by our set of independent variables.

The second set of regression models uses the insurers' issue-related changes in dynamic MES as the dependent variable. Again, regression (1) constitutes our baseline regression in which we use our full-sample of cat bond issues. Regression (1) shows that among the insurer characteristics, non-policyholder liabilities enter our regression with a significant negative sign. Non-policyholder liabilities are used to proxy for the insurers' financing activity outside the classical insurance business. The negative correlation between MES and non-policyholder liabilities result is economically significant since a one standard deviation increase in non-policyholder liabilities decreases the insurers' dynamic MES by 1.12% (0.080×0.140). Moreover, issue size enters our regression with a statistically significant negative coefficient which implies that large cat bond issues provide the issuers with more diversification benefits resulting in a decreased probability of default. Additionally, cat bonds covering mortality-related risks or medical benefit claims result in an increased exposure of the insurers' dynamic MES, though this effect is only weakly statistically significant.

In regression (2), we control for both the issuers' leverage as well as investment activity and exclude total assets. The results for our insurer characteristics show that both performance and IFRS have a significant positive effect on dynamic MES. One explanation could be that a better performance in the past could have increased stock volatility and therefore the exposure to systemic risk. Turning to cat bond related characteristics, indemnity-trigger based cat bond issues enter our regression with a statistically negative coefficient. This implies that an issuer of a cat bond using an indemnity-based trigger is well informed about the covered risks and could therefore reduce his exposure to overall systemic risk.

Again, model (3) includes the insurers' board structure and board independence as additional control variables. Most importantly, the results on non-policyholder liabilities as well as return on assets remain unchanged compared to of our previous estimations. Further, the issuers' investment activity has a statistically significant positive effect on dynamic MES. This result implicates that issuers investing more in assets rather than earning premiums from underwritings suffer from an increased exposure to systemic risk stemming from worldwide capital markets. Otherwise, the results for our cat bond related and country-specific variable estimates remain qualitatively unchanged.

Finally, we use the changes in ΔCoVaR as the dependent variable for our final set of regression models. We analyze, which factors help explain the issuing insurers' contribution to global systemic risk. Again, we consider the same set of independent variables as in our previous regressions. In regression (1), however, issuer size does not have a significant effect on the contribution of systemic risk, which indicates that size is neither a reasonable factor to determine the insurers' exposure nor the insurers' contribution to overall systemic risk. Turning to the insurers' profitability, the estimate for the variable Return on assets shows that higher issuer profitability has a statistically significant negative impact on the insurers' contribution to systemic risk. This relation is also highly economically significant with a one standard deviation increase in Return on assets increasing the change in ΔCoVaR by 0.26% (0.001×2.62). Moreover, performance enters our regression with a statistically significant negative coefficient which means that a good pre-issue performance increases the insurers' contribution to systemic risk. One possible explanation could be that a better stock performance is indicative of an increased risk taking by the insurer causing it to contribute more to systemic risk.

Interestingly, none of our cat bond characteristics can help explain the insurers' contribution to systemic risk. With regard to the country-characteristics, a higher GDP growth leads to an increase in ΔCoVaR and thus a decrease in the issuer's contribution to systemic risk.

Regression (2) constitutes the regression with the issuers' leverage, investment activity and excludes total assets due to multicollinearity problems. Consistent with our previous estimation results, a negative relation between the issuers' valuation and systemic risk can be found. The coefficient on the market-to-book value shows that an increase in the issuers' valuation leads to a decrease in ΔCoVaR. This effect is statistically and economically significant. Moreover, a higher leverage has a negative impact on the systemic risk contribution of issuers. It thus seems that leverage has a disciplining effect on managers, rather than a destabilizing effect on the financial sector due to increased risk-taking by the individual firm. Moreover, an increase in non-policyholder liabilities has a positive effect on the insurers' contribution to systemic risk. This result is in line with the findings of International Association of Insurance Supervisors (2012) and Weiß and Mühlnickel (2013). Again, performance has a positive effect on the insurers' contribution to systemic risk.

For the first time, the variable Loss ratio also enters our regressions with a significant negative coefficient. The issuers' loss ratio characterizes the quality of an insurance portfolio. We find that a higher loss ratio leads to a higher contribution to overall systemic risk by the issuing insurer. Also, previous issues seem to significantly affect the issuers' contribution to systemic risk. This variable enters our regression with a statistically significant positive coefficient and implies that insurers that have issued a large number of cat bonds in the past (and that are consequently more intertwined with the international financial markets) do not increase their contribution to systemic risk by means of a cat bond issue. Turning to the cat bond related variables, issue size enters the regression with a statistically significant negative coefficient and secured risk with a statistically significant positive coefficient. Both results are in line with the estimation results from regression (1) with the issue-related change in SRISK as our dependent variable.

The results for our country characteristics show that the Anti-Director Rights Index which is a proxy for shareholder protection enters our regression with a statistically significant positive coefficient. Insurers issuing cat bonds in countries with a higher shareholder protection can thus significantly decrease their contribution to systemic risk. Finally, regression (3) confirms our results for the insurer characteristics from regression (2). Additionally, the insurers' investment activity increases the contribution to systemic risk. This result is in line with the findings of Weiß and Mühlnickel (2013). Also, board size enters our regression with a statistically significant negative coefficient. Therefore, a larger board size tends to destroy firm value and possible capital buffers which results in insurers having a higher contribution to systemic risk. Again, the significantly higher adjusted R-squared values for our regressions using ΔCoVaR as our dependent variable show that a large portion of the cross-sectional variation in issue-related changes in issuers' ΔCoVaR can be explained by our set of independent variables.

Finally, we also estimate unreported regressions in which we include the maturity of the cat bonds, reinsurance prices, the maturity of the issuers' debt, the dummy variable for frequent issuers and the inflation rate. Our results remain qualitatively and quantitatively similar to the ones reported in Table V. In fact, several of these additional regressions are not successful due to significant multicollinearity. We also estimate regressions in which we substitute Total assets by Net revenues and Investment activity by Investment success. Our results remain unchanged. We also note that the linear correlation between the changes in MES and in ΔCoVaR is statistically insignificant. Followingly, both measures genuinely appear to measure two different aspects of an issuing insurer's systemic relevance: its exposure to systemic risk on the one hand, and its contribution to systemic fragility on the other hand.

4 Conclusions

In this paper, we conduct the first empirical assessment of claims that cat bond issues add to the contribution of the issuing insurer to the fragility of the financial sector. Theory provides inconclusive predictions regarding the relation between cat bond financing and systemic risk. On the one hand, cat bond issues enable the issuer to decrease its default risk as its susceptibility to catastrophe losses is reduced. Consequently, as defaults in the insurance industry become less likely, the financial sector as a whole should become more stable. On the other hand, cat bonds increase the interconnectedness of the issuer with other firms outside the insurance industry and consequently increase the counterparty risk present in the financial sector. Cat bonds could thus also contribute to increased levels of systemic risk, a view that is shared by insurance regulators seeking to reform the supervision of insurers in the wake of the near-collapse of AIG. We address these questions by analyzing a global sample of 176 cat bond issues that took place between December 1996 and April 2013 and by employing three measures of an issuing insurer's systemic relevance (SRISK, MES and ΔCoVaR) that capture both the insurer's exposure and contribution to systemic risk.

Our key result is in striking contrast to current conjectures of insurance regulators. Cat bond issues lead to economically significant decreases in the average issuer's contribution to systemic risk. Thus, cat bonds contribute to the stability of the financial sector rather than destabilize it. Conversely, cat bond issues do not significantly affect an insurer's exposure to externalities spilling over from other financial institutions during times of market turmoil. In addition to the positive side-effects on the issuers' individual default risk that has already been documented in the literature, we find additional evidence of a systemically stabilizing effect of these insurance-linked securities. This result holds when controlling for the systemic risk effects of non-issuing insurers. Our second key finding is that a higher pre-issue leverage, a higher firm valuation and previous cat bond issues all exert a decreasing effect on the issuer's systemic risk contribution.

The findings in this paper imply that insurance regulators, most notably the IAIS, should not penalize the use of cat bond financing with higher capital requirements as part of their endeavour to supervise globally systemically important insurers.

Appendix I: Sample Construction

The table shows the isolated impact of each single data filter we apply on our initial sample of cat bond issues as well as the combined effect of all filters. The initial sample is constructed by first selecting all insurers that issued cat bonds between December 1st, 1996 and April 1st, 2013. Data on cat bond issues are taken from *ARTEMIS* (www.artemis.bm). We apply a number of screens to focus on cat bonds issues with single and clearly specified triggers. We exclude issues where the underlying is not sufficiently specified or where the underlying type occurs only once in our sample. Further, we exclude issues with multiple trigger types, different maturities within tranches, and issues of non-insurance companies. Cat bond issues with unknown cedent or missing data on the trigger type are also excluded. We only consider issues for which the issuing insurer has quarterly accounting data in *Thomson Reuters Worldscope* and diurnal stock price data in *Thomson Reuters Financial Datastream*.

Sample / Filter	*Number of cat bond issues*	*% Lost*
Full sample (www.artemis.bm)	284	
Firms lost in single screens		
Insufficient specification of underlying	8	2.8%
Underlying type occurs only once	5	1.8%
Cat bond has multiple triggers	7	2.5%
No information on trigger available	4	1.4%
Cat bond has different maturities within tranches	4	1.4%
Cat bond issuer is a non-insurance company	6	2.1%
Cedent of cat bond is unknown	2	0.7%
Missing stock price data in *Datastream*	66	23.2%
Missing data on issue date	6	2.1%
Firms lost in combined screens	108	38.0%
Final Sample	176	
Sum of cat bond issue size (in $ billion)		
Full sample	49.3233	100.0%
Lost in combined screens	21.6204	43.8%
Final sample	27.7029	56.2%

Appendix II: Sample insurance companies.

The appendix lists all insurance companies that are used in the empirical study as well as the number of cat bond issues by a respective insurer. The sample is constructed by first selecting all insurers that issued cat bonds between December 1st, 1996 and April 1st, 2013 and then applying filters as described in Section 2. Data on cat bond issues are taken from *ARTEMIS* (www.artemis.bm). Company names and ticker symbols are retrieved from the *Thomson Reuters Worldscope* database. For the Japanese companies, custom mnemonics are used instead of the numerical ticker symbols of the Tokyo Stock Exchange. The sample includes 176 cat bond issues.

Firm	*Ticker Symbol*	*No. of issues*	*Firm*	*Ticker Symbol*	*No. of issues*
ACE American Insurance Co.	ACE	3	Lehman Re	LEHMQ	3
Aetna Life Insurance Company	AET	4	Liberty Mutual	LBH	5
AGF	AGF	1	Mitsui Marine & Fire	MMF	1
Allianz SE	ALV	7	Mitsui Sumitomo	MS	1
Allstate Corp.	ALL	2	Mitsui Sumitomo Insurance Co.	MSI	1
Amlin AG	AML	1	Montpelier Re Holdings	MRH	1
Argo Re	AGII	2	Munich Re Group	MUV2	15
Aspen Insurance Holdings	AHL	1	Nissay Dowa General Insurance	NDW	1
Assurant Inc.	AIZ	3	Platinum Underwriters Holdings	PTP	1
AXA S.A.	CS	3	PXRE Group	AGII	2
Catlin Group	CGL	3	SCOR SE	SCR	9
Chartis	AIG	4	Swiss Reinsurance Company	SREN	68
Chubb Group	CB	3	The Cincinnati Insurance Company	CINF	1
Converium	AGP	1	Tokio Marine & Nichido Fire Insurance	TMNF	2
Endurance Speciality Holdings	ENH	1	Travelers Companies	TRV	2
Flagstone Reinsurance Holdings	FSR	3	U.S. Fidelity & Guaranty Company	FG	2
Hannover Re	HNR1	3	Vesta Fire Insurance Group	VTAIQ	1
Hartford Financial Service Group	HIG	5	XL Mid-Ocean Re	XL	1
Hiscox	HSX	1	Zurich American Insurance Corporation	ZURN	6
Kemper	KMPR	1	Zurich Insurance Company	ZSA	1

Appendix III: Variable definitions and data sources.

The appendix presents definitions as well as data sources for all dependent and independent variables that are used in the empirical study. The insurer characteristics were retrieved from the *Thomson Reuters Financial Datastream* and *Thomson Worldscope* databases. The country control variables are taken from the World Bank's World Development Indicator (WDI) database. Data on cat bond issues are retrieved from the website www.artemis.bm.

Variable name	*Definition*	*Data source*
Dependent variables		
SRISK	Average annual estimate of the Systemic Risk Index as proposed by Acharya et al. (2012) and Brownlees and Engle (2012). The SRISK estimate for insurer i at time t is given by $SRISK_{i,t} = k(Debt_{i,t}) - (1-k)(1-LRMES_{i,t})Equity_{i,t}$ where k is a regulatory capital ratio (set to 8%), $Debt_{i,t}$ is the insurer's book value of debt, $LRMES_{i,t}$ is the long run Marginal Expected Shortfall defined as $1 - \exp(-18 \cdot MES)$, MES is the dynamically estimated Marginal Expected Shortfall and $Equity_{i,t}$ is the insurer's market value of equity.	Datastream, Worldscope (WC03351, WC08001), own. calc.
MES	Dynamic Marginal Expected Shortfall as defined by Acharya et al. (2010) and calculated following the procedure laid out by Brownlees and Engle (2012).	Datastream, own. calc.
ΔCoVaR	Conditional ΔCoVaR as defined by Adrian and Brunnermeier (2010), measured as the difference between the Value-at-Risk (VaR) of a country-specific financial sector index conditional on the distress of a particular insurer and the VaR of the sector index conditional on the median state of the insurer. As state variables for the computation of conditional ΔCoVaR, we employ the change in the three-month Treasury bill rate, the difference between the ten-year Treasury Bond and the three-month Treasury bill rate, the change in the credit spread between BAA-rated bonds and the Treasury bill rate, the return on the Case-Shiller Home Price Index, and implied equity market volatility from VIX.	Datastream, Chicago Board Options Exchange Market, Federal Reserve Board's H.15, S&P, own. calc.
Insurer characteristics		
Total assets	Natural logarithm of an insurer's total assets at fiscal year end.	Worldscope (WC02999).
Market-to-book	Market value of common equity divided by book value of common equity.	Worldscope (WC07210 and WC03501).
Leverage	Book value of assets minus book value of equity plus market value of equity, divided by market value of equity (see Acharya et al., 2010).	Worldscope (WC02999, WC03501, WC08001), own calc.
Investment activity	Ratio of the insurer's absolute investment income to the sum of absolute investment income and absolute earned premiums.	Worldscope (WC01002, WC01006), own calc.
Investment success	Ratio of the insurer's investment income to net revenues.	Worldscope (WC01001, WC01006), own calc.
Non-policyholder liabilities	Ratio of the total on balance sheet liabilities minus total insurance reserves (including benefit and loss reserves, unearned premiums, policy and contract claims and other reserves) to total liabilites.	Worldscope (WC03351, WC03030), own calc.
Net revenues	Log value of total operating revenue of the insurer.	Worldscope (WC01001).
Return on assets	Return of the insurer on its total assets.	Worldscope (WC08326).
Performance	Buy-and-hold returns of an insurer for the period from -252 to -20 days relative to the announcement date (%).	Datastream, own. calc.

Appendix II: Variable definitions and data sources. (continued)

Variable name	*Definition*	*Data source*
IFRS	Integer from one to 23 coding a firm's accounting standards according to Worldscope Database.	Worldscope (WC07536)
Loss ratio	Ratio of claim and loss expenses plus long term insurance reserves) to earned premiums.	Worldscope (WC15549).
Board size	Natural logarithm of the number of directors on an insurer's board.	ESG ASSET 4 (CGBSDP060).
Board independence	Percentage of independent outside directors on the board of directors.	ESG ASSET 4 (CGBSO07S).
Debt maturity	Total long-term debt (due in more than one year) divided by total debt.	Worldscope (WC03251 and WC03255).
Previous issues	Number of previous cat bond issues undertaken by the insurer.	Artemis.
Frequent issuer	Dummy variable that equals one if the issuer has issued five or more cat bonds during the observation period and zero otherwise.	Artemis.
Cat bond characteristics		
Issue size	Value of an issued cat bond scaled by the ceding insurer's book value of equity (%).	Artemis.
Maturity	Maturity of the cat bond in months.	Artemis.
Indemnity	Dummy variable that takes on the value one if the cat bond has an indemnity trigger and zero otherwise.	Artemis.
Secured risk	Dummy variable that takes on the value one if the cat bond securitizes mortality-related risks or medical benefit claims and zero otherwise.	Artemis.
Rating	The initial bond rating of the cat bond issue converted to a scale between 1 (best rating) and 19 (no rating). We follow Hagendorff et al. (2011) and convert the rating of an issue to a numerical value by assigning a value of one to issues rated AAA by S&P (or Aaa by Moody's), two to issues rated AA+ (Aa1), and so forth.	Artemis, Standard & Poor's, Moody's.
Country characteristics		
GDP growth	Annual real GDP growth rate (in %).	WDI database.
Inflation	Log of the annual change of the GDP deflator.	WDI database
Political stability	This indicator measures the perceptions of the likelihood that the government will be destabilized or overthrown by unconstitutional or violent actions. Indicator ranges from (-2.5) to (2.5). A higher indicator values indicates greater political stability.	WDI database.
HHI	Herfindahl-Hirschman Index computed as the sum of the squared market shares of a country's domestic and foreign insurers.	WDI database.
Anti-Director Rights Index	Anti-Director Rights Index of La Porta et al. (1998) as revised by Djankov et al. (2008) and Spamann (2010). The ADRI takes values from 0 to 5 with a higher value meaning better shareholder rights.	Spamann (2010).
Reinsurance prices	Guy Carpenter Rate On Line Index. The index is calculated by dividing global catastrophe reinsurance premiums by global catastrophe reinsurance limits.	Guy Carpenter.

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Tables and Figures

Figure 1: Size and number of catastrophe bond issues.

The figure shows the development of the total size and the number of catastrophe bond issues per year across our sample. The data are taken from *ARTEMIS* (www.artemis.bm) with the sample covering the time period between December 1st, 1996 and April 1st, 2013.

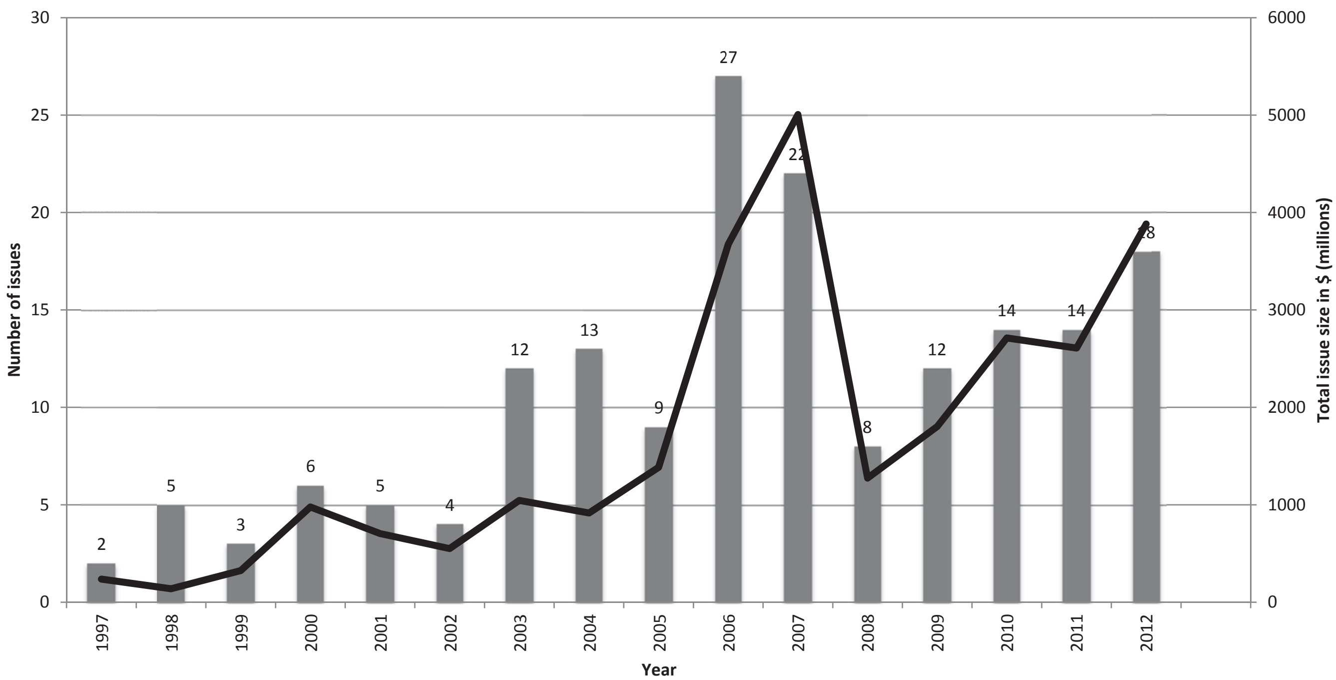

Table I: Summary statistics

The table presents summary statistics for the data used in our empirical analysis. The dependent variables represent changes in SRISK, MES and ΔCoVaR around cat bond issue dates. Variable definitions and data sources are provided in Appendix III.

	Obs.	Minimum	Maximum	5 % Quantile	95 % Quantile	Mean	Median	Standard deviation
Dependent variables								
- SRISK (in billions)	151	-24.97	69.37	-7.38	7.57	0.25	0.00	8.08
- MES	151	-0.8101	0.1209	-0.0510	0.0252	-0.0104	0.0003	0.0736
- ΔCoVaR	151	-0.1242	3.7813	-0.0353	0.0650	0.0344	0.0002	0.3159
Insurer characteristics								
- Total assets (in billions)	151	0.90	1,350.21	2.55	921.17	207.82	143.94	269.88
- Market-to-book	151	-0.76	4.50	0.02	2.38	1.22	1.20	0.76
- Leverage	151	0.08	126.34	1.82	27.23	10.13	5.65	16.35
- Investment activity	151	-0.18	0.46	0.03	0.30	0.16	0.15	0.08
- Investment success	151	-0.15	0.58	0.03	0.28	0.15	0.14	0.08
- Non-policyholder liabilities	151	0.08	0.77	0.10	0.64	0.29	0.26	0.14
- Net revenues (in billions)	151	5.57	8.15	6.02	8.09	7.31	7.44	0.56
- Return on assets	151	-19.71	10.20	-2.26	5.29	1.21	1.18	2.62
- Performance	151	-0.77	0.62	-0.37	0.41	0.02	0.03	0.24
- IFRS	151	1.00	23.00	1.00	23.00	7.32	3.00	9.16
- Loss ratio	126	0.32	1.76	0.51	1.06	0.85	0.84	0.22
- Board size	125	8.00	20.00	8.00	19.00	11.94	11.00	2.97
- Board independence	103	2.73	94.40	6.81	93.10	77.03	83.41	22.38
- Debt maturity	150	0.00	1.00	0.11	1.00	0.82	0.85	0.21
- Previous issues	151	0.00	65.00	0.00	59.00	15.61	5.00	19.71
- Frequent issuer	151	0.00	1.00	0.00	1.00	0.71	1.00	0.46
CAT bond characteristics								
- Issue size	151	6.00	550.25	11.00	400.00	153.17	134.00	118.36
- Maturity	84	12.00	71.88	18.00	48.00	37.39	36.00	9.69
- Indemnity	151	0.00	1.00	0.00	1.00	0.08	0.00	0.27
- Secured risk	151	0.00	1.00	0.00	1.00	0.06	0.00	0.24
- Rating	151	5.00	19.00	8.90	19.00	13.76	13.00	3.55
Country characteristics								
- GDP growth	151	-5.13	5.28	-3.53	4.16	1.76	2.42	2.04
- Inflation	151	-1.25	8.10	-0.68	3.32	1.31	0.83	1.48
- Political stability	150	0.04	1.39	0.04	1.39	0.90	1.03	0.40
- HHI	149	0.04	0.10	0.04	0.09	0.07	0.08	0.01
- Anti-Director Rights Index	151	2.50	5.00	2.50	5.00	3.05	3.00	0.53
- Reinsurance prices	142	70.00	255.00	98.00	235.00	153.07	145.00	37.94

Table II: Systemic risk changes around cat bond issues.

This table shows average differences in three different measures of systemic risk (SRISK (in $ million), MES and ΔCoVaR) around cat bond issues for the full sample of cat bond issues. The table includes the estimates for the three measures of systemic risk in the 180-day period before the announcement of the cat bond issue (pre-issue), the period after the issue (post-issue) and the difference between the two. Data on the cat bond issues are taken from ARTEMIS (www.artemis.bm) with the sample covering the time period between December 1st, 1996 and April 1st, 2013. Variable definitions and data sources are provided in Appendix III. P-values are given in parentheses. ***,**,* denote estimates that are significant at the 1%, 5%, and 10% level, respectively.

N	*Systemic risk measure*	*Pre-issue*	*Post-issue*	*Difference*
159	SRISK (in $ million)	7.854	8.051	0.196 (0.753)
162	Dynamic MES	0.053	0.044	-0.009* (0.092)
162	ΔCoVaR	-0.020	0.013	0.032 (0.180)

Table III: Systemic risk changes of issuers and matched non-issuing insurers around cat bond issues.

This table shows average differences in three different measures of systemic risk (SRISK (in $ million), MES and ΔCoVaR) around cat bond issues for issuing insurers and matched non-issuing insurers. Issuers and non-issuers are matched using propensity score (p-score) matching based on their (log) total assets. The table includes the estimates for the three measures of systemic risk in the 180-day period before the announcement of the cat bond issue (pre-issue), the period after the issue (post-issue) and the difference between the two. Data on the cat bond issues are taken from ARTEMIS (www.artemis.bm) with the sample covering the time period between December 1st, 1996 and April 1st, 2013. Variable definitions and data sources are provided in Appendix III. P-values are given in parentheses. ***,**,* denote estimates that are significant at the 1%, 5%, and 10% level, respectively.

		Issuer			*Matched non-issuer*			*Issuer vs. non-issuer*	
N	*Systemic risk measure*	*Pre-issue*	*Post-issue*	*Difference*	*Pre-issue*	*Post-issue*	*Difference*	*Difference*	*P-score*
121	SRISK (in $ million)	8.249	8.241	-0.008 (0.992)	7.837	8.113	0.276 (0.714)	0.284 (0.778)	-0.001 (0.408)
119	Dynamic MES	0.059	0.048	-0.011 (0.150)	0.067	0.051	-0.016** (0.044)	-0.005 (0.178)	-0.002 (0.103)
110	ΔCoVaR	-0.017	0.026	0.043 (0.229)	-0.019	-0.019	0.000 (0.986)	-0.043 (0.229)	-0.001 (0.223)

Table IV: Correlation matrix

This table presents the Bravais-Pearson correlation coefficients for our set of independent variables that are used in the cross-sectional analyses. Correlations that are significant at the 1% level are printed in bold type. Variable definitions and data sources are provided in Appendix III.

	Market-to-book	Leverage	Investment activity	Investment success	Non-policyholder liabilities	Net revenues	Return on assets	Performance	IFRS	Loss ratio	Board size	Board independence	Debt maturity	Previous issues	Frequent issuer	Issue size	Maturity	Indemnity	Secured risk	Rating	GDP growth	Inflation	Political stability	HHI	Anti-Director Rights Index	Reinsurance prices
Total assets	0.11	**0.59**	**0.42**	**0.31**	**0.40**	**0.62**	-0.06	-0.07	**0.42**	0.13	0.09	**-0.44**	**-0.35**	-0.03	0.13	0.26	-0.03	-0.10	-0.06	0.08	-0.06	-0.14	0.03	**-0.40**	**-0.32**	-0.15
Market-to-book		-0.22	0.07	0.02	-0.15	0.16	-0.01	0.00	0.10	0.09	0.28	**-0.31**	-0.02	-0.22	0.16	-0.06	-0.19	-0.04	-0.05	-0.13	0.23	-0.20	0.14	**-0.31**	**-0.33**	-0.19
Leverage			**0.34**	0.25	0.16	**0.35**	-0.09	0.00	0.16	0.09	-0.01	-0.10	-0.01	-0.08	-0.12	**0.40**	0.00	-0.08	-0.05	-0.03	**-0.30**	-0.06	-0.18	-0.22	-0.15	0.02
Investment activity				**0.95**	**0.31**	**0.42**	-0.04	0.12	0.17	**0.57**	-0.11	-0.16	-0.05	0.12	**0.41**	0.22	0.14	0.01	-0.11	-0.01	0.12	0.14	0.05	-0.19	-0.01	0.00
Investment success					0.25	**0.32**	-0.05	0.12	0.19	**0.52**	-0.13	-0.08	-0.02	0.11	**0.37**	0.21	0.11	0.04	-0.11	-0.01	0.14	0.21	0.02	-0.18	0.11	-0.01
Non-policyholder liabilities						0.14	-0.14	0.10	0.14	0.29	-0.24	-0.23	-0.16	-0.04	0.13	0.15	0.11	0.09	0.09	-0.04	0.10	**0.31**	-0.19	-0.06	0.18	0.18
Net revenues							0.04	0.01	0.22	0.10	0.24	-0.24	-0.07	0.25	**0.48**	0.13	0.19	-0.13	0.10	0.04	-0.13	-0.26	**0.41**	-0.25	**-0.46**	-0.12
Return on assets								0.16	-0.05	**-0.40**	0.25	0.11	0.05	0.00	-0.08	0.08	-0.03	0.29	0.14	-0.07	0.10	0.10	0.00	0.00	-0.05	0.11
Performance									-0.01	0.08	0.01	-0.03	0.03	0.06	0.10	0.09	-0.03	0.02	0.03	0.06	0.01	0.02	-0.08	-0.06	0.01	-0.01
IFRS										**0.34**	**0.60**	**-0.61**	0.10	**-0.32**	0.13	0.16	-0.03	0.08	-0.07	0.03	0.07	0.28	-0.26	**-0.78**	0.00	**-0.33**
Loss ratio											0.20	-0.18	0.16	-0.08	0.20	0.13	0.09	0.03	-0.03	0.00	0.22	0.23	-0.22	**-0.30**	0.28	-0.22
Board size												-0.25	0.29	-0.11	0.04	0.08	-0.05	-0.06	0.08	0.20	0.20	0.16	-0.25	**-0.60**	-0.27	-0.23
Board independence													0.20	**0.48**	0.04	-0.09	0.18	-0.02	0.12	0.19	0.01	-0.04	0.20	**0.50**	0.05	0.07
Debt maturity														-0.22	-0.08	0.03	0.03	0.14	0.01	-0.07	-0.07	0.21	-0.23	-0.10	-0.06	0.27
Previous issues															**0.49**	-0.05	0.22	-0.13	0.11	**0.39**	0.11	-0.20	**0.56**	0.19	-0.10	**-0.31**
Frequent issuer																-0.22	0.27	-0.19	-0.02	0.12	0.11	-0.12	**0.61**	-0.16	-0.17	**-0.39**
Issue size																	-0.10	0.09	0.25	-0.05	0.04	0.26	-0.29	-0.12	0.09	0.08
Maturity																		0.02	0.18	-0.11	-0.23	-0.02	0.26	0.21	0.06	0.10
Indemnity																			-0.07	-0.11	0.08	0.21	-0.07	0.03	0.16	0.07
Secured risk																				-0.19	-0.07	-0.04	0.03	-0.01	-0.05	0.02
Rating																					0.12	-0.02	0.13	-0.01	-0.01	-0.22
GDP growth																						0.27	-0.04	-0.07	0.16	-0.15
Inflation																							**-0.56**	-0.17	**0.50**	**0.38**
Political stability																								0.21	-0.29	**-0.42**
HHI																									0.10	**0.48**
Anti-Director Rights Index																										-0.11

Table V: Regression of the difference in a Cat bond issuer's exposure and contribution to systemic risk.

This table shows results from the cross-sectional regressions of the differences in three different measures of systemic risk around Cat bond issues. The dependent variables are the differences in the issuers' SRISK (in $ million), Marginal Expected Shortfall and ΔCoVaR. Variable definitions and data sources are provided in Appendix III. Model (1) represents our baseline regression in which we employ the issuers' total assets as an explanatory variable. Model (2) additionally employs the issuers' loss ratio and substitutes total assets by leverage and investment activity. Model (3) adds our two corporate governance variables instead of the loss ratio to the regression. All models are estimated with OLS. Newey-West heteroskedasticity and autocorrelation consistent *t*-test statistics are shown in parentheses. ***,**,* denote coefficients that are significant at the 1%, 5%, and 10% level, respectively.

Dependent variable	SRISK			MES			ΔCoVaR		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Panel A: Insurer characteristics									
Total assets	1.187			0.024			-0.002		
	(0.871)			(1.342)			(-0.344)		
Market-to-book	**-1.838***	-0.985	3.660	0.018	0.003	-0.008	0.005	**0.340****	**0.254****
	(-1.747)	(-0.877)	(1.287)	(1.096)	(0.754)	(-0.696)	(1.653)	**(2.221)**	**(2.076)**
Leverage		**0.129*****	**0.241*****		0.000	0.000		**0.010****	**0.003***
		(3.104)	**(2.730)**		(-1.304)	(-1.362)		**(2.098)**	**(1.956)**
Investment activity		-7.518	**-33.683***		0.018	**0.172****		-0.955	**-2.117***
		(-0.451)	**(-1.805)**		(0.543)	**(2.246)**		(-0.912)	**(-1.737)**
Non-policyholder liabilities	4.622	3.213	11.723	**-0.080***	0.005	**-0.134****	0.020	**-0.894***	-0.097
	(0.391)	(0.236)	(0.826)	**(-1.672)**	(0.275)	**(-2.233)**	(1.448)	**(-1.775)**	(-0.511)
Return on assets	-0.189	-0.089	**-1.486****	0.006	0.001	**0.007***	**0.001****	-0.020	**-0.097***
	(-1.255)	(-0.350)	**(-2.145)**	(1.256)	(1.189)	**(1.696)**	**(2.112)**	(-1.440)	**(-1.814)**
Performance	-7.155	-5.812	**-10.719***	0.021	**0.028*****	0.021	**-0.054***	**-0.175****	**-0.113***
	(-1.470)	(-1.171)	**(-1.890)**	(1.523)	**(2.671)**	(1.326)	**(-1.971)**	**(-2.101)**	**(-1.812)**
IFRS	**-0.251*****	**-0.214****	-0.264	0.001	**0.001*****	0.001	0.0003	**0.023****	0.012
	(-2.888)	**(-2.515)**	(-1.499)	(0.801)	**(3.017)**	(1.411)	(0.679)	**(2.121)**	(1.315)
Loss ratio		2.541			-0.004			**-0.550***	
		(0.447)			(-0.273)			**(-1.845)**	
Board size			0.297			-0.004			**-0.035***
			(0.466)			(-1.156)			**(-1.740)**
Board independence			-0.039			0.000			-0.003
			(-0.767)			(-0.213)			(-1.366)
Previous issues	-0.045	-0.029	0.054	0.000	0.000	0.000	0.000	**0.006****	**0.007***
	(-1.079)	(-0.749)	(0.985)	(0.885)	(1.084)	(-1.363)	(1.144)	**(2.233)**	**(1.668)**
Panel B: Cat bond characteristics									
Issue size	**0.019*****	**0.009****	**0.011***	**-0.001***	0.000	**-0.001***	0.000	**-0.001***	0.000
	(3.346)	**(2.002)**	**(1.915)**	**(-1.765)**	(-1.413)	**(-1.839)**	(0.086)	**(-1.718)**	(-0.271)
Indemnity	**2.110****	**5.013****	**6.814*****	-0.008	**-0.012***	-0.020	0.004	0.049	-0.085
	(2.077)	**(2.281)**	**(4.215)**	(-0.546)	**(-1.721)**	(-1.591)	(0.613)	(0.556)	(-0.777)
Rating	-0.080	-0.004	0.110	0.001	-0.0005	-0.001	0.000	0.009	0.004
	(-0.549)	(-0.029)	(0.668)	(0.898)	(-0.520)	(-0.664)	(0.224)	(1.211)	(0.775)
Secured Risk	**-4.457****	**-2.247***	-0.493	**0.031***	0.007	0.021	0.007	**0.236***	**0.117***
	(-2.271)	**(-1.703)**	(-0.240)	**(1.956)**	(0.917)	(1.628)	(0.579)	**(1.678)**	**(1.915)**
Panel C: Country characteristics									
GDP growth	**-0.786*****	**-0.810*****	**-0.923***	0.002	**0.002****	**0.005****	**-0.005*****	**-0.028****	-0.012
	(-3.018)	**(-2.657)**	**(-1.695)**	(0.909)	**(2.320)**	**(2.214)**	**(-4.439)**	**(-2.173)**	(-0.552)
Political stability	-0.440	1.516	-1.500	-0.041	-0.014	0.012	-0.014	-0.132	**-0.359***
	(-0.162)	(0.715)	(-0.495)	(-1.108)	(-1.654)	(0.937)	(-1.617)	(-1.135)	**(-1.941)**
HHI	**-158.854***	**-152.334***	-75.565	1.351	**0.772****	-0.499	-0.169	8.592	-0.685
	(-1.710)	**(-1.812)**	(-0.407)	(1.224)	**(2.463)**	(-0.723)	(-0.934)	(1.370)	(-0.111)
Anti-Director Rights Index	-0.851	0.866	-3.124	0.029	-0.007	0.0002	0.006	**0.664****	**0.674****
	(-0.465)	(0.520)	(-1.115)	(1.305)	(-1.622)	(0.012)	(1.465)	**(2.142)**	**(2.104)**
R^2	0.236	0.254	0.400	0.151	0.256	0.332	0.248	0.565	0.671
adj. R^2	0.148	0.134	0.270	0.053	0.136	0.187	0.161	0.494	0.600
number of observations	148	124	102	148	124	102	148	124	102