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The Risk Implications of Insurance Securitization: The Case of Catastrophe Bonds

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Abstract

Catastrophe (Cat) bonds are insurance securitization vehicles which are supposed to transfer catastrophe-related underwriting risk from issuers to capital markets. This paper addresses key, unanswered questions concerning Cat bonds and offers the following results. First, our findings show firms that issue Cat bonds exhibit less risky underwriting portfolios with less exposure to catastrophe risks and overall less need to hedge catastrophe risk. These results show that the access to the market for insurance securitization is easiest for firms with less risky portfolios. Second, firms that issue Cat bonds are found to experience a reduction in their default risk relative to non-issuing firms and our results, therefore, demonstrate that Cat bonds provide effective catastrophe hedging for issuing firms. Third, firms with less catastrophe exposure, increase their catastrophe exposure following an issue. Therefore, our paper cautions that the ability to hedge catastrophe risk causes some firms to seek additional catastrophe risk.

JEL codes: G22, G32, G33
Keywords: Insurance securitization, Catastrophe bonds, Default risk

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1. Introduction

Why firms choose to hedge, the effects of hedging on firm risk profiles and its implications for firm policy are important questions that a considerable literature in corporate finance has addressed over decades. In this paper, we add to this literature by analyzing the above questions for the case of catastrophe (Cat) bonds. Cat bonds are financial claims that protect the issuing firm from catastrophe losses by letting it forfeit on principal and/or coupon payments if a specified catastrophe loss event occurs (Cummins et al., 2002; Froot, 2001; Froot and O'Connell, 2008). Because Cat bonds relieve their issuers of some debt payments in the event of a natural catastrophe, their issue can be seen as a form of hedging against natural catastrophe risks. However, despite the fanfare with which Cat bonds were launched in the 1990s, Cat bonds have trailed expections as the total volume of Cat bonds outstanding has remained relatively modest to date. This raises important questions over if and how Cat bonds work as a hedge against catastrophe risks and, more broadly, what determines whether firms engage in insurance securitization.

The background to our paper is that firms with exposure to catastrophe risks have seen sharp increases in underwriting losses over recent decades. Crucially, the ability of insurers to finance these mounting catastrophe losses is uncertain mainly because the catastrophe underwriting capacity of the reinsurance markets, the conventional channel through which firms hedge their catastrophe exposures, is limited. Events such as the recent tsunami in Japan or Hurricane Katrina in 2005 have, therefore, default risk implications for individual insurers and can, potentially, cause distress in the global insurance markets if they bring about the default of an insurer or a series of insurers.

Partly in response to concerns over the default risk implications of natural catastrophes for insurers, insurance securitization vehicles such as Cat bonds, mortality bonds and sidecars have emerged which are supposed to transfer catastrophe risks from insurers to capital markets. Among these insurance securitization vehicles, Cat bonds have been by far the most commonly used insurance securitization vehicle with nearly $31 billion of risk capital (i.e. the total of bond principal and coupon payments at risk) issued between 1997 and 2010 (AON Capital Markets, 2010).[*] The total outstanding risk capital of Cat bonds issued between 1997 and 2010 corresponds to about 8% of insured catastrophe losses during that period.[†] While this makes Cat bonds a considerable risk transfer mechanism for hedging catastrophe risk, the total coverage via Cat bonds has remained behind earlier expectations that saw Cat bonds as a substitute to catastrophe reinsurance.

The low volumes of Cat bonds could partly be due to uncertainty over whether Cat bonds actually cause a significant transfer of catastrophe-related risk away from underwriters (Froot, 2001; Finken and Laux, 2009). There have long been concerns that a risk transfer may not occur or be of only negligible magnitude. This is because, even though Cat bonds exhibit some hedging properties, they rarely meet the conditions that make them a perfect hedge against catastrophe underwriting losses. For instance, there are suggestions that issuers only securitize

[*] The volume of Cat bonds has grown rapidly following the particularly disastrous U.S. hurricane season of 2005 ('Catastrophe-Bond Supply Builds Up', *The Wall Street Journal,* 27 September 2006). Increasingly, Cat bonds are also attracting the attention of retail investors ('Catastrophe Bonds: Ports and Storms', *The Economist,* 2 August 2007) as well as governments in developing countries seeking affordable ways of financing reconstruction in the aftermath of natural catastrophes ('Catastrophe insurance: When Calamity Strikes', *The Economist,* 21 January 2010).

[†] Based on the authors' calculations using Swiss Re Sigma Reports dating from 1997 to 2010. See also, 'Catastrophe bond offerings decline despite strong returns', *Financial Times,* 29 August 2008.

remote catastrophe risks.[‡] Consistent with this, few Cat bonds have caused losses for investors to date. This point is illustrated by Figure 1 which shows that the total returns for investors in Cat bonds (measured by the Swiss Re Global Cat Bond Total Return Index) have increased steadily despite highly volatile and generally increasing catastrophe losses realized by the insurance industry. Further, there is little association between Cat bond returns for investors and insured catastrophe losses. This is puzzling, because if Cat bonds were to offer a meaningful hedge against catastrophe-related underwriting risk, Cat bond returns and the catastrophe losses borne by the industry should be negatively related.

[Figure 1 near here]

A further factor which casts doubt on the ability of Cat bonds to reduce the default risk of their issuers is that the triggers which permit the issuers of Cat bonds to forfeit often do not match the specific loss experience of the issuer. Few Cat bonds use so-called indemnity triggers where payoffs are defined in terms of the issuer's realized losses. Instead, triggers (non-indemnity) are often defined in terms of industry-wide losses (e.g. via loss indices). Non-indemnity triggers give rise to basis risk which may leave insurers which have issued Cat bonds facing default in the event of high individual losses but low index losses (see Harrington and Niehaus, 1999; Cummins et al., 2004).[§]

The above concerns prompt us to ask three important questions around Cat bonds and insurer default risk. First, which type of firms issue Cat bonds in a given year? It is important to

[‡] Catastrophe bonds prove anything but a disaster, *Financial Times*, 2 June 2013.

[§] Both Harrington and Niehaus (1999) and Cummins et al. (2004) use simulation analyses to show that the basis risk linked to index-based triggers is manageable for U.S. homeowner insurers and large Hurricane insurers in Florida, respectively. However, it is important to bear in mind that these results are based on simulations. The risk that the payoffs from index-based Cat bonds do not cover the issuer's catastrophe losses remains a concern for issuing firms.

understand the default risk implications of Cat bonds in the context of why firms issue Cat bonds. For instance, if insurance securitization was conducted by firms with very risky portfolios or follows large loss events for the industry or individual firms, any reduction in default risk post-issue may be unrelated to a Cat bond reducing default risk and may instead be due to default risk simply reverting to its long-term equilibrium after a loss event.

Second, are Cat bonds effective in reducing insurer default risk and, if yes, do they indeed provide a hedge against catastrophe risk? It is important to bear in mind that Cat bonds could bring about a reduction in default risk not as a result of hedging catastrophe underwriting risks, but because of other risk-reducing attributes. For instance, unlike reinsurance, Cat bonds involve no counterparty risk. The pay-offs from Cat bonds for insurers are independent of the counterparty remaining solvent and Cat bond principals are fully collateralized (Lakdawalla and Zanjani, 2012).[**] Third, does hedging via insurance securitization affect underwriting behavior in the period following the issue of a Cat bond? If firms were to engage in a riskier underwriting strategy after they issued a Cat bond, this would raise the possibility of instability in global insurance and reinsurance markets if Cat bonds, though risk-reducing, cause some insurers to load up on more of the type of risks they have hedged via Cat bonds. In addressing these questions, this paper makes the following contributions.

[**] Further, Cat bonds shield issuers from volatile reinsurance premiums in the reinsurance markets where markets typically 'harden' and premiums increase rapidly following industry loss events (Froot and O'Connell, 2008; Cummins and Weiss, 2009). Cat bonds have a maturity of typically two to three years. This makes the cost of risk management via Cat bonds more predictable compared with reinsurance contracts which have a typical risk period of only one year. Consequently, the costs of coverage via Cat bonds are fixed for the issuer until the bond's maturity and remain fixed irrespective of underwriting losses realized by either the issuer or the industry. Since large loss events typically cause reinsurance markets to 'harden', leading to higher prices, the multi-year maturity of Cat bonds may shield insurers from unexpected hikes in the pricing of catastrophe risk management (or a loss of coverage if reinsurance pricing becomes too unattractive).

We provide the first empirical examination into the determinants of firms issuing Cat bonds. Existing theory on this subject has come to conflicting predictions as regards, for instance, whether issuers have portfolios with a high potential for underwriting losses (Subramanian and Wang, 2013) or less risky portfolios (Gibson, Habib and Ziegler, 2011). Our results show that firms which issue Cat bonds have less catastrophe risk exposure and lower risk portfolios overall and, therefore, back explanations that access to the market for insurance securitization is easiest for firms with less risky portfolios. Put differently, our results show that Cat bonds issuers typically are not firms with high-risk or high-exposure portfolios in need to offload catastrophe risk to the financial markets.

Second, we present the first empirical investigation into the realized risk implications of insurance securitization. Previous work on the risk implications of Cat bonds is based on simulations (Cummins et al., 2004; Harrington and Niehaus, 2003) and pointed out the various other risk-based effects of Cat bonds which are not necessarily linked to hedging catastrophe risk (Lakdawalla and Zanjani, 2012; Cummins and Weiss, 2009; Froot and O'Connell, 2008). We show that Cat bonds reduce the default risk of issuing firms relative to firms that do not issue Cat bonds and, crucially, that this risk reduction is in part caused by hedging againsts catastrophe risks. Further, because our empirical approach simulteneously observes issuing and non-issuing firms as well as the reasons for why firms issue a Cat bond, we are able to deal with the potential endogeneity of a firm’s decision to issue a Cat bond in a standard two-step approach. While our main results are based on a probability of default indicator (based on the Merton model), our results are robust to using total market risk or credit default swap (CDS) yields as alternative measures of risk.

Finally, our results also identify some of the drivers and consequences of the risk reduction benefits of Cat bond issues. We show that the risk reduction benefits associated with insurance securitization are more pronounced during time periods when the supply of reinsurance as a substitute to catastrophe risk management is restricted. Further, almost all firms with little exposure to catastrophe risks before they issue a Cat bond will take on additional catastrophe risk in the two years following insurance securitization. Thus, many firms, after hedging, will load up on more of the type of risk they have hedged.

The rest of the paper proceeds as follows. The next section describes the Cat bond sample. Section 3 analyzes the determinants of when firms issue Cat bonds. This is followed by an analysis of the default risk implications of Cat bond issues in Section 4. Finally, Section 5 analyzes how Cat bond issues affect catastrophe underwriting behavior in the years following an issue before Section 6 concludes.

2. Sample and Cat Bond Data

Our sample includes all insurance and reinsurance firms listed on Datastream with accounting data available on Worldscope. This yields a sample of 274 firms from 1997 to 2010. We then identify firms which have issued Cat bonds using proprietary data from Hannover Re which cover all Cat bond issues before May 2010. Cat bonds are defined as bonds where coupons and/or principal payments are contingent on the occurrence of catastrophe-related property and casualty risks or catastrophe-related mortality risks.[††] In all cases, the issuer is the ultimate beneficiary of the Cat bond coverage.[‡‡]

[††] Catastrophe mortality risks result from catastrophe events which generate spikes in mortality rates (e.g. terrorist attacks or pandemics). While we include these so-called mortality (Cat) bonds in the sample, we exclude longevity

For an initial list of 143 Cat bond issues, we verify the Cat bond data from Hannover Re by matching them with publicly available information on insurance securitizations in AON Capital Markets (2010) and Guy Carpenter (2008). Where discrepancies between proprietary and public data (as regards the issue date, value and risks underlying an issue) are identified, we try to resolve these by conducting searches on various news sources available on LexisNexis and Factiva. Where the discrepancies remain unresolved, we omit the affected issue from our sample (this affects a total of seven issues).

[Table 1 near here]

We then omit issues for any one of the following reasons. First, when a firm issues more than one Cat bond in the same fiscal year, the transactions are consolidated into a single issue. This way, we lose 38 observations (mostly when repeat issues are made on the same day or within a matter of days)[§§]. Second, we drop so-called follow-up transactions from shelf offering programs. Shelf offering programs allow firms to issue further Cat bonds at any time. Follow-up transactions tend to be very small and have only a limited amount of information available. This affects 29 issues.

Overall, we identify 69 Cat bond issues for our analysis. Table 1 provides an overview of the Cat bond issues by year and country. It becomes evident that the majority of Cat bond transactions took place after 2006 and that most Cat bonds were issued by firms listed in the U.S., Switzerland, and Germany.

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bonds. This is because longevity bonds securitize longevity risk (due to increased life expectancy) and are not linked to catastrophe events (for more details, see Cowley and Cummins, 2005).

[‡‡] Transactions where the Cat bond coverage is sold by the issuer to a third party (i.e. Calabash Re Ltd. I-III by Swiss Re) are not included in the sample to avoid convoluted interpretations of our results.

[§§] For all cases where Cat bond transactions are consolidated, the trigger types of the individual transactions are identical.

3. The Determinants of Cat Bond Issues

We start our investigation by analyzing which firms issue Cat bonds in a given year. It is important to understand when firms are likely to issue Cat bonds. Since firms self-select to issue a Cat bond, they are likely to differ from firms that do not issue Cat bonds in ways that may be relevant for the risk implications of insurance securitization. For instance, if insurers are more likely to opt for securitization if their insurance portfolios are risky, any reduction in default risk post-issue may be unrelated to a Cat bond reducing default risk and may instead due to portfolio risk reverting to its long-term mean after an issue.

We are not aware of empirical work that has analyzed the determinants of firms issuing a Cat bond. Existing theory work on this subject has come to conflicting predictions as regards for instance whether issuers have portfolios with a high potential for underwriting losses (Subramanian and Wang, 2013) or less risky portfolios (Gibson, Habib and Ziegler, 2011). To understand which firms issue Cat bonds in a given year, we estimate the following probit model:

$$Pr(CATBOND_{it}=1)=(\mathbf{TC}_{it-1}, \mathbf{MC}_{it-1}, e_i), \tag{1}$$

where $CATBOND_{it}$ takes the value of one during the fiscal year that an insurance firm has issued a Cat bond (and zero otherwise), $\mathbf{IC}_{it-1}$ and $\mathbf{MC}_{it-1}$ are vectors of issuer and market controls (observed at the end of the fiscal year before the issue year t) and e_i is a random error term.

3.1 Issuer Characteristics

The vector of issuer controls in (1) includes the issuers' profitability (**ROA**; defined as pre-tax profits scaled by total assets). More profitable insurers should find it easier to build up reserves as loss buffers in order to manage catastrophe-related underwriting risks (De Haan and Kakes, 2010). More profitable insurers should hence be less likely to issue a Cat bond. We control for issuer size (**SIZE**) which is measured by the logarithmic transformation of the issuers' total assets. We expect firm size to enter the model with a positive coefficient because larger companies possess the adequate mass to produce transactions of sufficient scale to amortize the high structuring costs of Cat bonds (Cummins and Trainar, 2009) and because the basis risk involved in transactions is likely to decrease with the size of the issuing firm (Harrington and Niehaus, 1999).

Next, we include various risk measures because the extant theory-based literature makes conflicting predictions as regards the effect of insurer risk on Cat bond issues. Citing supply side factors, Subramanian and Wang (2013) argue that high-risk insurers opt for securitization over reinsurance as a risk transfer mechanism. Reinsurers posses superior resources over capital markets to monitor insurers and overcome adverse selection problems that result from insurers holding private information about their portfolios. This implies that catastrophe coverage is relatively costly via reinsurance for high-risk insurers. Risky insurers, that is, insurers with a higher prospect of underwriting losses, will therefore be the more likely issuers of catastrophe bonds.

By contrast, Gibson, Habib and Ziegler (2011) cite demand side factors in the Cat bond market to argue that risky insurers will be less likely to issue Cat bonds. The authors argue that, when insurance losses are uncertain, it will be costly for insurers to issue Cat bonds to investors.

Given the prospect of adverse selection for investors if issuers are risky (investors do not have access to the private information that underlies insurer portfolios), investors in Cat bonds by risky issuers will insist on a high yield to compensate them for dealing with an informed counterparty. Hagendorff et al. (2013) present results which are consistent with this prediction

We include the following risk measures in our models. The first three measures are derived from regressions that relate the stock returns of individual firms to the MSCI World Index and the global volume of insured catastrophe losses (from Swiss Re Sigma reports) over a three-year rolling window. First, we use the factor loadings on the MSCI World Index as a measure of market risk (**MKTBETA**). The variability (risk) of stock returns can be decomposed into (undiversifiable) market and (diversifiable) firm-specific risk components for each firm. Higher values of MKTBETA indicate that firms are more exposed to market risk.

Second, we use the factor loadings on insured catastrophe losses from the same regressions to inform us how exposed a firm is to catastrophe underwriting losses. To ease the interpretation of the factor loadings, we replace positive factor loadings with zeros and take absolute values of the remaining factor loadings. That way, the measure captures firm value losses linked to industry catastrophe losses. We call the resulting measure **CATEXPOSURE**. Third, **HIGHCATEXPOSURE** indicates firms which are particularly exposed to catastrophe risk as indicated by firms being located in the top 40% of the sample distribution of CATEXPOSURE.[***] Finally, we include two more variables to capture the risk of the issuer's insurance portfolio. First, **LOSSRATIO** is the sum of claim expenses, loss expenses and long-term insurance reserves scaled by earned premium income. Second, underwriting risk

[***] The results we report are not sensitive to how we define HIGHCATEXPOSURE. The results we report remain qualitatively unchanged if we define firms as highly exposed to catastrophe risk if they are located in the top 40%, 30%, 25%, or 10% of catastrophe exposure in the sample.

(**UWRISK)** is the standard deviation of LOSSRATIO over a four-year period before the issue announcement (also employed in de Haan and Kakes, 2010). Finally, we include a probability of default measure (**PD**, based on a Merton model as described in Section 4.2) to directly capture the default risk of insurance firms.

We also control for the issuing firm's **LEVERAGE** which is defined as total liabilities over total assets. Since securitization is a means to free up capital that can be used to absorb losses and lower the prospect of financial distress following a large loss event (Cummins and Trainar, 2009), highly leveraged firms should, therefore, be more likely to issue Cat bonds.

We include measures of insurer **DIVERSIFICATION** (measured as the percentage of sales which do not stem from insurance premiums (1-[premiums written/net sales]), operating efficiency (**EXPENSERATIO**; underwriting expenses/premiums written) and Tobin's Q (**TOBQ,** defined as a firm's market-to-book ratio) as a proxy for a firm's future growth opportunities. Both cost efficiency and Tobin's Q can, in a wider sense, be understood as measures of managerial quality with better managed firms either more or less likely to issue Cat bonds. For instance, Gay and Nam (1998) argue that poor managers may be more likely to engage in hedging activities in order to mask their ability and the quality of their projects.

Finally, we control for whether the firm is a **REINSURANCE** firm. Since we expect reinsurance to have greater exposure to catastrophe tail risks than insurance firms, we expect reinsurance firms to be more likely to be amongst the issuers of Cat bonds.

3.2 Market Characteristics

Moving on to the vector of market characteristics, we use the Guy Carpenter (2010) Rate On Line Index (**REPRICES**) as a measure of reinsurance prices. This yearly index is calculated by dividing global catastrophe reinsurance premiums by global catastrophe reinsurance limits. REPRICES, therefore, measures average reinsurance prices per unit of catastrophe risk underwritten.

Reinsurance markets tend to follow cycles which are characterized by periods when reinsurance prices are relatively low and coverage is readily available (soft markets), and periods when reinsurance prices are high and coverage supply is restricted (hard markets) (see Jaffee and Russell, 1997; Niehaus, 2002). During hard reinsurance markets, insurers will only be able to make limited use of catastrophe reinsurance and are more reliant on Cat bonds as a risk transfer mechanism. For some types of catastrophe events, no reinsurance capacity may be available during hard reinsurance markets, which means that Cat bonds will be the only vehicle for insurers to hedge their catastrophe-related underwriting risk. Owing to the lack of reinsurance capacity during hard reinsurance markets, we expect more Cat bond issues during hard reinsurance markets (when REPRICES is high). Consequently, we expect REPRICES to enter the model with a positive sign.

We control for the influence of economic growth on the risk implications of insurance securitization by including the inflation-adjusted national GDP growth rates (**GDP**). If recessions decrease demand for insurance in general, we expect a negative sign between GDP and the probability of a Cat bond issue. We control for industry underwriting losses (**GLOBALINSLOSSES**) caused by natural catastrophes. Specifically, we use the yearly total of insured catastrophe losses (as published in Swiss Re Sigma Reports). We expect industry losses to be positively associated with Cat bond issues. Larger industry losses should lead to capacity constraints in reinsurance markets, thus making Cat bonds more attractive as a risk transfer mechanism.

Finally, we include a measure of *potential* catastrophe losses. It is likely that the prospect of future catastrophe losses, rather than actual industry losses, causes greater awareness of natural perils amongst insurers and increases the demand for risk transfer mechanisms such as Cat bonds. To capture potential catastrophe losses, we employ an index of storm activity in the Atlantic and Pacific by using the Accumulated Cyclone Energy (ACE) index as published by the National Oceanic and Atmospheric Administration (NOAA). Our variable **POTENTIAL-LOSSES** equals one if the NOAA classified a storm season 'above normal' using ACE index values.[†††]

[Table 2 near here]

Table 2 presents summary statistics and shows that our sample contains a large and heterogeneous sample of insurance and reinsurance firms. The table shows that the average probability of default is 0.80%, 10% of sample firms are reinsurance firms and around one in three years during our sample period is characterised as above normal storm seasons.

[†††] The index measures the number of storm systems, how long they existed and how intense they became. ACE index values in excess of 120% of the median value over the preceding 30 years are classified as an 'above normal season' by the NOAA. While the index captures only wind-based catastrophe risks in the U.S., these are the dominant perils underlying Cat bonds by far (because they are the most capital-intensive perils in global insurance markets). To illustrate this, our sample contains only eight Cat bonds with no exposure to either U.S. risks and to wind risks. Therefore, if natural catastrophes lead to more demand for Cat bonds, irrespective of whether they cause insured losses for an insurer, this effect should be particularly so for the type of event and geography that underlies the vast majority of Cat bonds. The index is published at http://www.aoml.noaa.gov/hrd/tcfaq/E11.html.

3.3 Results: The Determinants of Cat Bond Issues

The results of our prediction models of which firms issue a Cat bond in a particular year are presented in Table 3. The first four columns present the results using probit models while the last column uses an OLS model for added robustness.

Perhaps our most surprising finding relates to the risk profile of Cat bond issuers. A series of variables indicate that insurers with less risky portfolios are more likely to issue a Cat bond. Thus, Cat bond issuers exhibit lower market risk, lower loss ratios, lower underwriting risk and, perhaps most importantly, lower exposure to natural catastrophes (measured both via the factor loading on catastrophe losses and a binary variable indicating a particularly high factor loading). While most measures of insurer portfolio risk enter below the 10% level individually, F-tests reveal that they are jointly statistically significant at the 1% level. These findings jointly point towards low-risk insurers issuing Cat bonds and are clearly in conflict with the view that insurance securitization is conducted by insurers with risky portfolios.

[Table 3 near here]

We argue the finding that low risk insurers issue Cat bonds is consistent with the notion of Cat bond investors demanding higher yields from riskier issuers which, therefore, make Cat bonds relatively unattractive for high-risk insurers relative to other catastrophe risk management channels (see Gibson et al., 2011). Since investors do not have access to the private information that underlie insurer portfolios and the true nature of the risks being securitized, it is likely that they will use publicly available information (such as the unpredictability of insurance losses or the exposure to catastrophe risk and other measures similar to the ones we employ above) as proxies for the true riskiness of an insurer's portfolio. If Cat bond investors demand higher yields in line with publicly observable risk measures, Cat bonds will be less attractive for this type of insurer compared to reinsurance. Because reinsurance firms have superior monitoring capabilities compared with investors, they will be able to price premiums more closely in line with the true insurance portfolio risk of an insurer, thus, making reinsurance, rather than securitisation, the preferred risk transfer choice for seemingly risky firms.

There is also some evidence that firms are more likely to securitize following increases in industry insured losses caused by catastrophes as well as increases in our measure of potential wind-based losses. Therefore, uncertainty and potential underwriting losses are drivers of insurance securitization, not only realized underwriting losses. Further, reinsurance and larger firms are more likely to issue a Cat bond (all coefficients enter significantly at the 1% level). This is consistent with explanations that reinsurance firms have greater exposure to catastrophe tail risks and are thus more likely to employ Cat bonds as a way to hedge these risks. Further, larger firms have capacity to amortize the relatively high costs of a Cat bond issue. Finally, firms with more growth opportunities (higher TOBQ) are less likely to issue a Cat bond, which is consistent with the view that poor managers may be more likely to engage in hedging activities in order to mask their ability and the quality of their projects (Gay and Nam, 1998).

In summary, the findings of the prediction models show that firms which issue a Cat bond differ from firms which do not engage in insurance securitization as regards their risk profile and other firm characteristics. Also, the timing of Cat bond issues depends on catastrophe loss events for the industry—both realised and potential losses. Both the firm and the market characteristics of Cat bond issuers we report in Table 3 have implications for the risk effects of insurance securitization as we explain below.

4 The Risk Implications of Issuing a Cat bond

4.1 Identification Strategy

In this section, we examine how effective Cat bonds are in transferring default risk from insurers to capital markets. The premise of our analysis is that, if Cat bonds provide an effective risk transfer, we expect the issuing firm's default likelihood to decrease in response to the issue of a Cat bond.

Our analysis of when firms issue Cat bonds has uncovered various industry- and firm-specific factors as determinants of Cat bond issues. Our analysis will therefore have to deal with two resulting issues to produce unbiased estimates of the risk effects of Cat bond issues. First, there may be industry-wide factors that affect firms that issue a Cat bond and firms that do not issue a Cat bond equally. For instance, our analysis above uncovers that issues follow industry loss events. Any reduction in default risk after the issue may therefore be simply a return to normal market conditions that could otherwise be incorrectly attributed to the issue of a Cat bond. Second, the decision to issue a Cat bond is jointly determined with a number of factors which are internal to the firm. Indeed, we show above that insurance portfolio risk and firm size are determinants of insurance securitization. It is therefore likely that past values of firm variables and other variables which are unobservable, and therefore uncontrollable for us, are determinants of insurance securitization. Not accounting for this potential source of endogeneity will bias our estimates of the default risk effects of Cat bonds.

To deal with both issues, we observe the default risk of firms that have issued Cat bonds and firms that have not issued Cat bonds simultaneously to account for omitted variables which may affect issuing and non-issuing firms. We then employ a two stages least squares (2SLS) procedure to be able to also observe the reasons why firms issue in a particular year. The 2SLS procedure first estimates the fitted values of the prediction model reported in Column D of Table 3 to yield $CATBOND^*$, before estimating the following model of the default risk implications of issuing a Cat bond.

$$PD_{it} = \alpha + \beta_{it} CATBOND^*_{it} + \gamma' \mathbf{IC}_{it-1} + \delta' \mathbf{MC}_{it-1} + \gamma_i + \gamma_t + \varepsilon_{it} \quad (2)$$

Where PD_{it} is the probability of default for firm *i* at time *t*. PD_{it} is based on a Merton model of default risk (described in Section 4.2). $CATBOND^*_{it}$ are the fitted values of the prediction results of which firms issue Cat bonds in a particular year. Since PD relies on market data to produce a measure of expected risk, a one-year period is sufficient to fully capture changes in risk due to securitization as it is reasonable to assume that market prices will have adjusted to reflect changes in market prices in a short time period.[‡‡‡,§§§] $\mathbf{IC}_i$ is a vector of issuer characteristics at the end of the fiscal year before the issue announcement; and $\mathbf{MC}_i$ is a vector of market specific characteristics and γ_i and γ_t control for unobserved random and time effects. The control variables are the same as in (1). We provide additional detail on how we treat the potential endogeneity of CATBOND below in Section 4.3.

[‡‡‡] In some cases, announcements of Cat bond issues precede the issue date and, hypothetically speaking, this could lead to cases where issues are announced and completed in different fiscal years. We hand collect the dates on which Cat bond issues were first announced in the press by searching various news sources on LexisNexis and Factiva, as well as the issuing firms' websites and ARTEMIS (www.artemis.bm), an online practitioner portal for insurance securitization. We then confirm that for all the Cat bond issues in our sample, the announcement date falls within the same fiscal year as the issue date. Also, none of the issues in our sample are announced later than in October, leaving sufficient time for market prices to adjust during the same fiscal year to reflect the issue of a Cat bond.

[§§§] In untabulated tests, we redefine CATBOND to equal one for two years after the issue of a Cat bond. We find qualitatively identical results; that is, CATBOND enters significantly and negative (with the magnitude of the coefficient on CATBOND somewhat but not drastically lower).

4.2 Measuring the Probability of Default

To estimate the effect of Cat bonds on the issuers' default risk, we apply the Merton (1974) option pricing method. This default risk measure has recently been employed by Furfine and Rosen (2011) and Hagendorff and Vallascas (2011) to study the default risk implications of mergers and acquisitions. In later analyses, we demonstrate that our main findings hold when we use stock market volatility or the credit default swap (CDS) yields on senior bonds as alternative risk measures. The Merton default risk measure has several advantages over other risk measures. First, the measure can be calculated for all listed firms and not only for a subset of firms (as with the case of CDS spreads). Second, because it draws on market data, the Merton default risk measure picks up the expected risk benefits at the time of the issue even though these benefits will materialize at a future point in time.

The daily default risk of issuing firms is estimated using the following probability of default risk (PD):

$$PD_t = N\left(-\frac{\ln(V_{A,t} / L_t) + \left(rf_t - 0.5\sigma^2_{A,t}\right)T}{\sigma_{A,t}\sqrt{T}} \right), \qquad (3)$$

where $V_{A,t}$ is the market value of assets on day t, L_t is the book value of total liabilities and, rf_t is the risk-free rate (proxied by the annualized yield on two-year government bonds in the issuer's country), $\sigma_{A,t}$ is the annualized asset volatility on day t, T is the time to maturity (conventionally set to one year), and N is the cumulative density function of the standard normal distribution.

The computation of PD requires estimates of $V_{A,t}$ and $\sigma_{A,t}$, neither of which are directly observable. We simultaneously estimate the values of $V_{A,t}$ and $\sigma_{A,t}$ through an iterative process based on the Black-Scholes-Merton option pricing method. Specifically, we view the market value of a firm's equity ($V_{E,t}$) as a call option on the value of the firm's assets by solving the following system of nonlinear equations:

$$V_{E,t} = V_{A,t} N(d_1) - L_t e^{-rftT} N(d_{2,t}) \text{,} \tag{4}$$

$$\sigma_{E,t} = \left(V_{A,t} N(d_{1,t}) \sigma_{A,t}\right) / V_{E,t} \text{,} \tag{5}$$

where,

$$d_{1,t} = \frac{\ln(V_{A,t} / L_t) + \left(r_{f,t} + 0.5\sigma^2{}_{A,t}\right)T}{\sigma_{A,t}\sqrt{T}}, \quad d_{2,t} = d_{1,t} - \sigma_{A,t}\sqrt{T} \tag{6}$$

Equation (3) is the optimal hedge equation that relates the standard deviation of a firm's equity value to the standard deviation of a firm's total asset value (both on an annualized basis).

To solve the system of nonlinear equations, we first employ as starting values for $\sigma_{A,t}$ the historical volatility of equity (computed daily on the basis of a 90-trading day rolling window) multiplied by the square root of the number of trading days in the year. We then use the daily values of $\sigma_{E,t}$ and $V_{E,t}$ to compute the initial value of $\sigma_{A,t}$ as $\sigma_{A,t} = \sigma_{E,t} V_{E,t} / (V_{E,t} + L_t)$. Finally, a Newton search algorithm identifies the daily values of $V_{A,t}$ and $\sigma_{A,t}$ which we then employ to compute the default likelihood for each issuer per day in (3).

4.3 Results: The Default Risk Implications of Issuing a Cat Bond

Table 4 reports our main results. In all regressions, we use our panel of insurance and reinsurance firms and exploit variation in the issue of Cat bonds across firms and time to estimate the effect of issuing a Cat bond on firm default risk. In all models, CATBOND, the variable which indicates whether firms issued a cat dummy enters negatively and significantly (below the 1%-level). This presents clear evidence that the issue of a Cat bond leads to a reduction in default risk.

The various columns in Table 4 differ so that we can demonstrate that our main result is robust to both the possibility of Cat bond issues being endogenously determined with insurer risk and robust to different techniques of treating this potential endogeneity. Column A uses a simple OLS model, while Column B uses the 2SLS regression approach which employs the fitted values of the prediction model in Column D of Table 3 for CATBOND. This approach requires us to identify an instrument that is related to the decision to issue a Cat bond in a particular year, but not to the probability of default of insurance firms.

[Table 4 near here]

As our results in Table 3 show, U.S. wind activity (captured by the ACE index and denoted by POTENTIAL-LOSSES) is a valid instrument as it is one of the statistically significant determinants of Cat bond issues (almost all Cat bonds are exposed to U.S. wind perils and more wind activity will cause greater awareness of such perils amongst insurers and increase demand for risk transfer mechanisms such as Cat bonds). However, to be a valid instrument, the ACE index should not affect the default risk of our international sample of insurers after controlling for firm and industry losses (as we do in Table 4). In unreported tests, we confirm that there are indeed no statistically significant differences in firm default risk between periods with above normal wind seasons and other wind seasons. U.S. wind activity does not affect default risk because, (i) we measure wind levels (in t-1) and risk (in t) with a time lag of one year and (ii) a large proportion of the economic losses caused by U.S. wind activity are not insured and therefore do not cause underwriting losses for insurers.

Arguably, a clear-cut external instrument for a firm's decision to issue a Cat bond is difficult to identify. Therefore, Columns E and F of Table 4 use a different instrumental variable approach to treat the potential endogeneity of the Cat bond variable. We estimate our model using a dynamic panel based on a Generalized Method of Moments (GMM) estimator as proposed by Arellano and Bond (1991) and recently applied by Wintoki, Linck and Netter (2012) to deal with endogeneity issues in corporate finance research.[****] The advantage of using a GMM estimator is that we can treat endogeneity without the need to identify external instruments. GMM uses information on a firm's history (using lags and differences in insurer characteristics such as the decision to issue a Cat bond, risk exposures, etc.) as instruments for current insurer characteristics. A second advantage of the GMM approach is that it can account for the dynamic nature of risk. As we demonstrate below, previous risk is an important factor in explaining current values of risk and not accounting for this will bias any estimation of the risk effect linked to the issue of a Cat bond.[††††]

[****] Following Blundell (2002), we use on the one-step GMM estimator. We do not use a system GMM estimator (Blundell and Bond, 1998), because untabulated tests reject the validity of the additional moment conditions (i.e. the level conditions).

[††††] Since we cannot rely on the Sargan statistic as a model specification test for the GMM estimation (due to the presence of heteroskedasticity, detected using a test proposed by Pagan and Hall (1983)), we justify the validity of the instruments using a test of second-order correlation. If we included enough lags to control for the dynamic aspects of our empirical relationship and if the assumptions of our specification are valid, by construction the

The results presented in Table 4 are clear. Cat bond issues cause a reduction in default risk. This result holds using a simple ordinary least squares OLS regression (which does not account for endogeneity of the Cat bond variable), or alternatively using the 2SLS or the dynamic GMM regressions (which both account for endogeneity of CATBOND). Therefore, our main conclusion is that, regardless of whether or how we treat endogeneity concerns surrounding the issue of a Cat bond, our finding that Cat bonds reduce the default risk of issuing firms remains unchanged.

It is interesting to point out that the coefficient on CATBOND in Column B of Table 4 increases substantially compared with either the coefficients based on simple OLS or the GMM estimations in Columns C-E. This is because the IV approach in Column B replaces the binary (0-1) values of CATBOND with the predicted values of CATBOND. Since the predicted values are on average smaller than the binary values, the coefficient on the predicted values of CATBOND are larger in Column B.

The results in Table 4 also show that high catastrophe exposure is one of the factors entering significantly, confirming that high levels of catastrophe risk exposure have default risk implications for the insurance and reinsurance industry. We also control for market risk which means the coefficients measure the effect on default risk after controlling for systematic risk components. Market risk enters with the expected positive sign.

residuals in first differences (AR(1)) should be correlated, but there should be no serial correlation in second differences (AR(2)). The m1 and m2 statistics confirm this.

4.4 Robustness: Different Risk Measures

We conduct several tests to evaluate the robustness of our main result that Cat bonds lower the default risk of issuers. First, we assess whether or not our main conclusion holds if we employ two different measures of risk. Table 5 uses both total risk (measured as the standard deviation of monthly returns over one year) and credit default swap (CDS) spreads (on five-year senior bonds in local currency) from Bloomberg. As standard in the literature, we select CDS contracts with a maturity of five years because these contracts are the most liquid. Bloomberg constructs a composite quote referred to as Bloomberg Generic which is an arithmetic average of the CDS spreads offered by various market participants and which has the advantage of being insensitive to the evaluation of one market participant alone.

[Table 5 near here]

The table shows both the results of the models predicting which firms issue Cat bonds (Columns A and C) and the results of the 2SLS procedure which estimates the effect of Cat bonds on risk. Despite total risk being a different risk measure (it captures the investment risk for equity holders rather than default risk) and despite CDS spreads being available for only 58 out of our 274 sample firms, we can replicate our key results. Most importantly, CATBOND enters with a negatively and statistically significant coefficient (below 10%).

Given the clear risk reduction benefits of Cat bonds, an important question is how such risk reductions are achieved. The next subsection analyzes if the risk benefits of Cat bonds are moderated by the risk profile of the issuing firm or the trigger type underlying the Cat bond.

4.5 When Do Cat Bonds Reduce Risk?

In this subsection, we analyse some of the conditions under which Cat bonds reduce the default risk of issuing firms. For instance, it is important to know whether or not the risk reduction benefits linked to the issue of a Cat bond are indeed related to a firm's catastrophe risk exposure or whether the risk reduction benefits vary by type of Cat bond (indemnity versus non indemnity). We do so by introducing a vector of interaction terms to the following equation:

$$PD_{it} = \alpha + \beta_1 CATBOND_{it} + \beta_2 CATBOND_{it} \times \mathbf{INTER} + \gamma' \mathbf{IC}_{it-1} + \gamma_i \, \delta' \mathbf{MC}_{it-1} + \gamma_i + \gamma_t + \varepsilon_{it} \qquad (7)$$

Where β_1 captures the average effect of Cat bond issues on the issuer's probability of default (PD) and β_2 any additional risk effect linked to certain Cat bond or market characteristics (INTER). We allow the effect of Cat bonds on the PD to depend on HIGHCATEXPOSURE, indemnity-based triggers (INDEM=1, zero otherwise), time periods of high (low) reinsurance prices (HIGHPRICES [LOWREPRICES]), and Cat bond ratings.

We estimate (7) using GMM so that we do not have to identify additional external instruments for the (potentially endogenous) interaction terms. After all, there is the distinct possibility that, besides CATBOND, other explanatory variables are endogenous. GMM accounts simultaneously for the potential endogeneity of CATBOND as well as the Cat bond characteristics which we capture using internal instruments. For instance, the choice of which type of trigger to include in a bond is likely to be endogenous as an insurer has no reason to issue a bond with a trigger it expects to be at most weakly related to losses by the insurer. All variable definitions are as before.

The results in Table 6 show the following. The interaction term between CATBOND and HIGHCATEXPOSURE enters negatively (significant below 1%) showing that issuers which are highly exposed to catastrophe underwriting risk experience a larger reduction in default risk following the issue of a Cat bond. On average, highly exposed firms reduce their default risk by around 8% following the issue of a Cat bond (firms which are not highly exposed experience a default risk reduction of around half this magnitude).

[Table 6 near here]

The fact that the risk reduction benefits of Cat bonds increase in high catastrophe risk exposure is an important finding, because it demonstrates that one of the channels through which Cat bonds reduce risk is by hedging catastrophe-related underwriting risk. Ultimately, Cat bonds have various other features which are potentially risk-relevant (for instance, Cat bonds facilitate liquidity management by making the cost of catastrophe coverage more predictable over longer time periods) and it is not clear a priori whether the risk reduction benefits of Cat bonds are caused by catastrophe exposure or by other risk-relevant features of insurance securitization.

Our interpretation that Cat bonds are an effective hedge against catastrophe-related default risk is further supported by the fact that the interactions involving HIGHCATEXPOSURE and INDEM also enter negatively and significantly. Cat bonds can be designed using either indemnity-based or non-indemnity based triggers. For indemnity-based triggers, Cat bond payoffs depend on the actual loss experience of the issuer's own business. By contrast, the payoffs from Cat bonds linked to non-indemnity-based triggers are defined in terms of industry-wide losses (via loss indices) which may vary substantially from the underwriting losses realized by the issuer. As a result, non-indemnity-based triggers give rise to basis risk which rises the more the insured losses of the issuer and the index losses diverge. Since indemnity-based triggers do not involve any basis risk, they serve as a perfect hedge against catastrophe-related underwriting losses (Harrington and Niehaus, 1999; Cummins et al., 2004).

Our results in Columns F and G of Table 6 show that indemnity based issues reduce the default risk only if issuing firms are highly exposed to catastrophe underwriting risk. Columns G and H in Table 7 show that these types of Cat bonds reduce the probability of default of the issuing firm by around 20%. Otherwise, indemnity-based issuances reduce the default risk to the same magnitude as non-indemnity based issues. We interpret the presence of risk reduction benefits linked to Cat bonds without an indemnity-based trigger as an indication that the basis risk underlying these issues is not sufficiently large as to prevent the risk reducing effects of Cat bonds from materializing.

[Table 7 near here]

Prices in the reinsurance market also affect changes in the default likelihood in response to Cat bond issues. The interaction between Cat bond and HIGHPRICES enters with a negative and statistically significant coefficient (significant at the 5% level). This indicates that Cat bond issues during periods of high reinsurance prices lead to larger reductions in the default likelihood of issuing firms. We argue that hard reinsurance markets (when the supply of catastrophe coverage via reinsurance is restricted) make insurers more reliant on Cat bonds as a vehicle to hedge catastrophe risk and that this is likely to incentivize insurers to design Cat bonds such that they maximize the potential hedging benefits to them.

Finally, Table 7 presents the results of additional interactions. The table is presented in abbreviated form with only the coefficients on CATBOND and on the interactions displayed. The results of these additional interactions show that the risk reduction benefits of Cat bonds are stronger for reinsurance firms (consistent with the view that reinsurers manage more catastrophe risks than insurers). Further, the default risk implications of Cat bonds do not differ for firms based in the U.S. or firms based in Switzerland (both countries make sizable contributions to the sample) and between before the crisis and after the crisis.

In summary, we find the following. Cat bond issues reduce the default risk of issuing firms and they do so by a larger degree if issuing firms are highly exposed to catastrophe underwriting risk and when highly-exposed firms issue an indemnity-based Cat bond. This is consistent with the view that Cat bonds offer an effective hedge against catastrophe-related underwriting risks and that the risk-reduction benefits of issuing Cat bonds are linked to the underwriting risks (and less so other risk relevant Cat bond attributes).

In the next section, we analyze the final of our three main research questions, namely if firms that hedge catastrophe risks using Cat bonds alter their underwriting behavior in the time period following Cat bond issues.

5 Do Cat Bond Issues Affect Catastrophe Underwriting Behavior?

In this final section, we investigate how Cat bond issues affect catastrophe underwriting behavior in the years following an issue. We are interested to see how firm underwriting behaviour following Cat bond issues differs for firms which display high and low exposure to catastrophe risks. Our analysis above shows that high-exposure firms realize additional risk reductions from issuing Cat bonds relative to firms with less catastrophe exposure. However, the risk reduction effect of Cat bonds may be short-lived if firms engage in more aggressive catastrophe underwriting behaviour in the period following an issue. In other words, catastrophe hedging may make firms seek additional risk exposure to the type of risk they have previously hedged via Cat bonds.

Figure 2 shows changes in the catastrophe risk exposures of high-exposure issuers (Panel A) and low-exposure issuers (Panel B). As previously, high catastrophe exposure firms are firms with a factor loading on their stock return sensitivity to insured industry catastrophe losses which is above 60% of the sample distribution. Changes in catastrophe risk exposures are measured one year before the issue relative to one year after the issue of a Cat bond.[‡‡‡‡] While Panel A shows that Cat bond issues were followed by a reduction in catastrophe exposure for most firms (consistent with explanations that Cat bonds are an effective catastrophe hedge), Panel B shows that most firms with low catastrophe exposure pre-issue increased their catastrophe exposure post-issue. The increase in catastrophe exposure amongst low-exposure firms is extremely widespread. Nearly all firms with low catastrophe exposure increase their catastrophe exposure in the years following an issue.

[Figure 2 near here]

A joint reading of these results and the results reported in the previous section shows that, while high-risk firms are intent on hedging catastrophe risk (they lower default risk and default risk exposures in the years following a Cat bond issue), low risk firms seek additional catastrophe risk exposure in the years following insurance securitization. This could be due to firms with low exposure writing catastrophe risks on a scale in the post-issue period they would have not considered before issuing a Cat bond. It may even be a strategy by some firms to hedge their existing catastrophe underwriting risks using Cat bonds before they seek to grow their catastrophe underwriting business. Either way, it appears that firms with little catastrophe exposure seek more risk of the type they have hedged using Cat bonds.

[‡‡‡‡] We observe qualitatively identical patterns over a two-year period.

Whether or not the increased catastrophe risk exposure of some firms in the years following the issue of a Cat bond is a cause for concern is not obvious from our analysis. It is true that low-exposure firms do not increase their default risk when issuing a Cat bond (as shown in Table 6, Column B). However, the increased catastrophe risk exposure could prove problematic in the future if natural catastrophes occur more frequently in the next few years than forecasted at the time the catastrophe risks were underwritten. Models that determine the likelihood of natural perils such as hurricanes can be prone to error and are frequently revised. For instance, if hurricanes were to strike the U.S. more frequently than forecasted at the time the additional catastrophe risk was underwritten by our sample firms, the additional catastrophe exposure could give rise to large and currently unexpected underwriting losses.

6 Summary and Conclusions

Catastrophe-related underwriting activities are a source of default risk for insurance and reinsurance firms. Traditionally, reinsurance contracts have been the only instrument for insurers to transfer the underwriting risk linked to catastrophes. More recently, Cat bonds have emerged as an alternative risk transfer instrument. While the market for Cat bonds has undergone rapid growth, the overall volume of Cat bonds outstanding to date has remained lower than expected.

The aims of our analysis are threefold. We examine the factors that determine the decision of a firm to issue a Cat bond; we study the risk implications of Cat bond issues; and we analyze the catastrophe underwriting behavior of insurers in the time period following an issue. Our main insights are as follows. First, Cat bonds are issued by firms with low risk underwriting portfolios and less exposure to catastrophe underwriting risk rather than by firms with highly risky portfolios seeking to hedge their catastrophe exposure. This suggests that seemingly risky issuers have less access to the market for insurance securitization. Second, our paper provides the first empirical evidence that Cat bonds 'work' by showing that the issuers' default risk decreases in response to the Cat bond issue and, crucially, that this reduction is at least in part due to firms reducing their exposure to catastrophe related underwriting risks.

Finally, our analysis shows that when firms with relatively little underwriting exposure issue a Cat bond, they increase their catastrophe underwriting risk following the issue. This more aggressive catastrophe underwriting behavior in the years following a Cat bond issue is widespread amongst low-risk firms and it raises the spectre of instability in global insurance and reinsurance markets if Cat bonds, though risk-reducing, cause low-risk insurers to load up on more of the type of risks they have hedged via Cat bonds.

Three main policy implications arise from our findings. First, since Cat bonds are clearly associated with a risk reduction for insurers, their use should be encouraged by regulators. This is particularly important given the increasing systemic relevance of a number of large insurance firms (Billio et al, 2012, Cummins and Weiss, 2010). Second, our analysis of the determinants of insurance securitization shows that insurers with low risk-risk portfolios are much more likely to issue a Cat bond. This raises the question whether high-risk and high-exposure insurers, in effect the type of firms that stand most to benefit from hedging via Cat bonds, are shut out of the market for insurance securitization. Thus, improved and more detailed disclosure of the types of catastrophe risks securitized and on the existing portfolio of insurance risk should create additional transparency to help overcome adverse selection concerns by investors.

Third, the adoption of Cat bonds should be encouraged by regulators irrespective of the underlying trigger type. Presently, solvency regulations only permit issuers of Cat bonds with indemnity triggers to treat Cat bonds like reinsurance (and hold lower reserves against the associated underwriting risks). This is because regulators are concerned that non-indemnity triggers involve basis risk which thwarts risk transfers which are sufficiently large to warrant lower capital holdings. Our results are at odds with the present regulatory treatment of Cat bonds, because our results show that non-indemnity based Cat bonds also reduce the default risk of the issuer. Therefore, insurance regulators should extend some form of favorable solvency treatment to non-indemnity based Cat bonds.

While we report risk reduction benefits in response to the issue of Cat bonds, it is likely that the risk benefits of Cat bonds go beyond individual insurers. For instance, the global insurance and financial industry may have become less vulnerable to systemic distress as a result of more insurers engaging in insurance securitization. Future research should, therefore, examine the systemic stability effects of Cat bonds. Finally, while our default likelihood approach picks up expected changes in default risk around the time that a Cat bond is issued, it would equally be useful to understand the realized default risk implications of a large natural catastrophe. For instance, future research could examine the default risk effects of the recent Japanese earthquake on firms with underwriting exposure to this catastrophe and gauge if the risk effects were mitigated for insurers which have issued Cat bonds.

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Table 1. Catastrophe Bonds Included in the Sample

By Year		By country of the issuing firm	
1997	1	France	10
1998	3		
1999	2	Germany	15
2000	4		
2001	4	Japan	4
2002	3		
2003	1	Switzerland	15
2004	1		
2005	5	UK	3
2006	9		
2007	12	US	22
2008	9		
2009	10		
2010	5		
TOTAL	69	TOTAL	69

Based on proprietary data from Hannover Re and Aon Capital Markets.

Table 2. Descriptive Statistics

Variable	Definition	Obs	Mean	St.Dev	25Pctile	75Pctile
PD	Probability of default (%)	1,859	0.802	6.414	0.000	0.012
ROA	Return on assets (%)	1,859	1.973	3.574	0.463	3.318
SIZE	Log of total assets (thousands of US)	1,859	15.697	2.131	14.099	17.141
MKTBETA	Market beta using a three-year rolling two factor model with the MSCI World Index and global insured losses (from Swiss Re)	1,859	0.731	0.851	0.043	1.325
CATEXPOSURE	We use the factor loading on global insured losses based on a three-year rolling two-factor model with the MSCI World index and global insured losses (from Swiss Re). We replace positive factor loadings with zeros and take the absolute values the remaining factor loadings.	1,859	0.421	1.377	0.041	0.505
HIGHCATEXPOSURE	Equals 1 if CATEXPOSURE is in the highest 40% of the sample distribution (zero otherwise).	1,859	0.400	0.481		
LOSSRATIO	(claims and loss expenses+ long-term insurance reserves)/ premiums earned (%)	1,859	97.76	134.23	36.70	205.41
UWRISK	Standard deviation of loss ratio over a four-year period	1,859	5.900	6.492	1.230	7.630
LEVERAGE	Total liabilities to total assets (%)	1,859	78.883	14.398	71.354	90.138
DIVERSIFICATION	1-(premiums written/net sales)	1,859	0.202	0.354	0.058	0.310
EXPENSERATIO	Underwriting expenses/premiums written (%)	1,859	0.165	1.685	0.036	0.121
TOBQ	Market value of equity/book value of equity	1,859	1.688	3.393	0.950	1.770
REINSURANCE	Equals 1 if the firm is a reinsurer	1,859	0.104	0.305		
REPRICES	Reinsurance Cycle. Guy Carpenter World Catastrophe Rate on Line Index. Source: Guy Carpinter (2010)	1,859	226.789	42.686	205.000	255.000
GDP	Real GDP growth	1,859	4.485	2.353	3.690	6.174
GLOBALINSLOSSES	Global Insured Catastrophe Losses (in logs) from Swiss Re Sigma Reports	1,859	9.297	1.194	8.713	10.040
POTENTIAL-LOSSES	Equals 1 if storm season in the Atlantic and Pacific is classified as 'above normal' by the NOAA	1,859	0.313	0.464		

The sample consists of 258 firms over the period 1997 to 2010. Accounting data are cross-sectional averages for the sample period and are from Worldscope. GDP are from IMF International Financial Statistics database.

Table 3. The Determinants of Issuing a Cat bond

	A	B	C	D	E	F
			Probit			OLS
ROA	-0.009	0.017	0.032	0.024	0.030	0.0004
	[0.037]	[0.038]	[0.039]	[0.041]	[0.045]	[0.001]
SIZE	0.492***	0.461***	0.485***	0.479***	0.488***	0.021*
	[0.089]	[0.09]	[0.095]	[0.097]	[0.101]	[0.011]
MKTBETA	-0.127**	-0.130*	-0.128*	-0.105	-0.107	-0.004*
	[0.063]	[0.066]	[0.068]	[0.071]	[0.071]	[0.002]
CATEXPOSURE	-0.114	-0.136*	-0.141*			
	[0.078]	[0.077]	[0.08]			
HIGHCATEXPOSURE				-0.337*	-0.365*	-0.017**
				[0.200]	[0.206]	[0.008]
LOSSRATIO	-0.007**	-0.007*	-0.007*	-0.007*	-0.007*	0.000
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]	[0.000]
UWRISK	-0.009*	-0.008	-0.010*	-0.010*	-0.010*	0.000
	[0.005]	[0.005]	[0.006]	[0.006]	[0.006]	[0.000]
PD					0.004	
					[0.008]	
LEVERAGE	-0.013	-0.007	-0.008	-0.008	-0.008	-0.001
	[0.012]	[0.013]	[0.013]	[0.013]	[0.014]	[0.001]
DIVERSIFICATION	-0.151	-0.173	-0.189	-0.184	-0.171	-0.005
	[0.151]	[0.146]	[0.144]	[0.145]	[0.150]	[0.010]
EXPENSERATIO	-0.01	-0.017	-0.018	-0.021	-0.023	-0.001
	[0.057]	[0.051]	[0.048]	[0.048]	[0.048]	[0.002]
TOBQ	-0.111*	-0.115*	-0.125*	-0.124*	-0.136*	-0.002
	[0.062]	[0.066]	[0.067]	[0.069]	[0.069]	[0.002]
REINSURANCE	1.011***	0.996***	1.039***	1.064***	1.087***	
	[0.313]	[0.309]	[0.324]	[0.334]	[0.348]	
REPRICES		-0.001	0.001	0.001	0.001	0.001
		[0.003]	[0.003]	[0.003]	[0.003]	[0.000]
GDP		-0.059*	0.017	0.033	0.03	0.001
		[0.036]	[0.043]	[0.043]	[0.044]	[0.002]
GLOBALINSLOSSES		0.027	0.202*	0.211**	0.198*	0.010**
		[0.09]	[0.105]	[0.106]	[0.108]	[0.005]
POTENTIAL-LOSSES			0.774***	0.814***	0.793***	0.030***
			[0.257]	[0.261]	[0.268]	[0.01]
Constant	-8.934***	-8.850***	-11.581***	-11.761***	-11.666***	-0.320**
	[1.346]	[1.604]	[1.901]	[1.924]	[1.955]	[0.139]
Observations	1,974	1,974	1,974	1,974	1,859	1,974
Number of firms	274	274	274	274	258	274
R-squared						0.021
Pseudo-Rsquared	0.164	0.172	0.196	0.197	0.198	
Time effects	Yes	Yes	Yes	Yes	Yes	Yes
Unobserved effects	Yes	Yes	Yes	Yes	Yes	Yes

This table reports Probit regressions (columns A-E) and an OLS regression (column E) to explain which firms issue a Cat bond. The variables are as defined in Table 2. We report robust standard errors in parenthesis. Significance levels are denoted as *** p<0.01, ** p<0.05, *p<0.1.

Table 4. The Effect of Cat Bonds on Firm Probability of Default

	A	B	C	D	E	F
	OLS	**IV**	**OLS**	**OLS**	**GMM**	**GMM**
PD(t-1)			0.123***	0.127***	0.091***	0.092***
			[0.026]	[0.026]	[0.027]	[0.027]
ROA	-0.047	-0.003	-0.025	-0.027	-0.054	-0.057
	[0.061]	-0.11	[0.061]	[0.061]	[0.076]	[0.076]
SIZE	0.246	1.691	0.318	0.24	1.845**	1.710**
	[0.428]	[1.029]	[0.425]	[0.426]	[0.778]	[0.78]
MKTBETA	0.387***	0.171	0.335***	0.346***	0.466***	0.446***
	[0.089]	[0.19]	[0.089]	[0.09]	[0.102]	[0.102]
HIGHCATEXPOSURE	0.902***	0.016	0.807***	0.854***	1.111***	
	[0.308]	[0.693]	[0.307]	[0.307]	[0.352]	
LOWCATEXPOSURE						-0.932***
						[0.347]
LOSSRATIO	0.001	0.001	0.001	0.001	0.001	0.001
	[0.002]	[0.004]	[0.002]	[0.002]	[0.003]	[0.003]
UWRISK	-0.002	-0.002	-0.002	-0.002	-0.003	-0.003
	[0.003]	[0.006]	[0.003]	[0.003]	[0.004]	[0.004]
LEVERAGE	0.008	-0.063	0.003	0.006	-0.038	-0.036
	[0.032]	[0.066]	[0.032]	[0.032]	[0.051]	[0.051]
DIVERSIFICATION	0.123	0.176	0.114	0.111	0.039	-0.006
	[0.427]	[0.76]	[0.424]	[0.425]	[0.533]	[0.534]
EXPENSERATIO	-0.026	-0.072	-0.023	-0.021	-0.067	-0.066
	[0.064]	[0.116]	[0.064]	[0.064]	[0.069]	[0.069]
TOBQ	0.045	-0.102	0.041	0.049	-0.017	-0.007
	[0.077]	[0.154]	[0.076]	[0.076]	[0.087]	[0.088]
REPRICES	-0.001	0.002	-0.002	-0.002	0.003	0.004
	[0.005]	[0.008]	[0.005]	[0.005]	[0.007]	[0.007]
GDP	-0.213***	-0.372**	-0.160**	-0.149**	-0.256***	-0.264***
	[0.069]	[0.145]	[0.07]	[0.07]	[0.087]	[0.087]
GLOBALINSLOSSES	-0.115	0.003	-0.135	-0.142	-0.076	-0.107
	[0.155]	[0.281]	[0.154]	[0.154]	[0.201]	[0.201]
CATBOND	**-3.290*** **	**-58.870*** **	**-3.103*** **		**-4.738*** **	**-4.791*** **
	[0.949]	**[26.725]**	**[0.944]**		**[1.062]**	**[1.063]**
Observations	1,859	1,859	1,859	1,859	1,471	1,471
Number of firms	258	258	258	258	237	237
R-squared	0.035		0.049	0.043		
Time effects	Yes	Yes	Yes	Yes	Yes	Yes
Unobserved effects	No	Yes	No	No	Yes	Yes

This table reports OLS regressions (columns A,C,D); the second stage of 2SLS (column B) based on column C of Table 3; and first-stage of Arellano-Bond GMM estimators (columns E and F). The dependent variable is probability of default (PD). All variables are defined in Table 2.We report robust standard errors in parenthesis. Significance levels are denoted as *** p<0.01, ** p<0.05, * p<0.1.

Table 5. Alternative Risk Measures

	A	B	C	D
	Probit CATBOND	**IV** TOTALRISK	**Probit** CATBOND	**IV** CDS
ROA	0.024	-0.012***	0.281	-0.034
	[0.041]	[0.002]	[0.19]	[0.473]
SIZE	0.479***	-0.043**	0.636***	-3.037
	[0.097]	[0.021]	[0.188]	[4.14]
MKTBETA	-0.105	0.042***	-0.107	0.039
	[0.071]	[0.004]	[0.147]	[0.533]
HIGHCATEXPOSURE	-0.337*	0.024	-0.921***	-2.878
	[0.2]	[0.015]	[0.351]	[1.823]
LOSSRATIO	-0.007*	0.000	-0.008	0.003
	[0.004]	[0.000]	[0.007]	[0.006]
UWRISK	-0.010*	0.000	-0.01	-0.001
	[0.006]	[0.000]	[0.009]	[0.009]
LEVERAGE	-0.008	0.002	0.043	-0.054
	[0.013]	[0.001]	[0.047]	[0.277]
DIVERSIFICATION	-0.184	-0.016	-1.917**	0.858
	[0.145]	[0.016]	[0.901]	[3.202]
EXPENSERATIO	-0.021	0.001	0.229	-0.654
	[0.048]	[0.003]	[0.672]	[2.035]
TOBQ	-0.124*	-0.006*	-0.445	-0.41
	[0.069]	[0.003]	[0.326]	[1.315]
REINSURANCE	1.064***		1.184**	
	[0.334]		[0.494]	
REPRICES	0.001	0.000	0.044	0.26
	[0.003]	[0.000]	[0.03]	[0.16]
GDP	0.033	-0.028***	-0.017	0.749**
	[0.043]	[0.003]	[0.061]	[0.348]
GLOBALINSLOSSES	0.211**	0.005	1.277*	5.836
	[0.106]	[0.006]	[0.727]	[3.743]
POTENTIAL-LOSSES	0.814***		0.924**	
	[0.261]		[0.403]	
CATBOND		**-0.893***		**-31.890***
		[0.528]		**[17.359]**
Constant	11.761***	0.870***	39.373***	-55.344
	[1.924]	[0.25]	[14.758]	[67.62]
Observations	1,973	1,973	316	316
Time Dummies	Yes	Yes	Yes	Yes
Unobserved effects	Yes	Yes	Yes	Yes
Number of firms	274	274	58	58

This table reports 2SLS results. The first stage is based in Probit regressions (columns A and C) where the dependent variable is CATBOND. The second stage is reported in columns B and D, where column B uses CDS as the dependent variable and column D uses TOTAL RISK. We report robust standard errors in parenthesis. Significance levels are denoted as *** p<0.01, ** p<0.05, * p<0.1.

Table 6. The Effect of Cat Bonds on the Probability of Default: Interaction terms

	A	B	D	E	F	G	H
PD(t-1)	0.127***	0.084***	0.131***	0.148***	0.076***	0.138***	0.134***
	[0.028]	[0.027]	[0.028]	[0.029]	[0.027]	[0.028]	[0.028]
ROA	-0.059	-0.052	-0.061	-0.049	-0.044	-0.089	-0.096
	[0.08]	[0.076]	[0.08]	[0.079]	[0.075]	[0.081]	[0.081]
SIZE	2.003**	1.887**	1.951**	2.079**	1.702**	1.971**	2.070**
	[0.818]	[0.779]	[0.818]	[0.808]	[0.78]	[0.82]	[0.822]
MKTBETA	0.450***	0.460***	0.443***	0.442***	0.442***	0.423***	0.426***
	[0.103]	[0.102]	[0.104]	[0.102]	[0.102]	[0.104]	[0.104]
HIGHCATEXPOSURE	0.434	1.051***	0.440	0.376	1.116***	0.392	0.380
	[0.367]	[0.353]	[0.367]	[0.363]	[0.351]	[0.369]	[0.369]
LOSSRATIO	0.000	0.001	0.000	0.000	0.001	0.000	0.000
	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
UWRISK	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
LEVERAGE	-0.024	-0.039	-0.019	-0.022	-0.027	-0.024	-0.035
	[0.054]	[0.051]	[0.054]	[0.053]	[0.051]	[0.054]	[0.054]
DIVERSIFICATION	0.491	-0.002	0.522	0.469	0.039	0.562	0.525
	[0.592]	[0.534]	[0.592]	[0.584]	[0.532]	[0.594]	[0.594]
EXPENSERATIO	-0.083	-0.069	-0.079	-0.105	-0.063	-0.073	-0.085
	[0.085]	[0.069]	[0.085]	[0.084]	[0.068]	[0.086]	[0.086]
TOBQ	-0.045	-0.018	-0.047	-0.042	-0.019	-0.045	-0.042
	[0.091]	[0.087]	[0.091]	[0.089]	[0.087]	[0.091]	[0.091]
REPRICES	0.017**	0.003	0.017**	0.018**	0.001	0.017**	0.017**
	[0.008]	[0.007]	[0.008]	[0.008]	[0.007]	[0.008]	[0.008]
GDP	-0.209**	-0.264***	-0.209**	-0.279***	-0.199**	-0.212**	-0.217**
	[0.087]	[0.087]	[0.087]	[0.086]	[0.089]	[0.087]	[0.087]
GLOBALINSLOSSES	0.202	-0.064	0.196	0.244	-0.07	0.183	0.185
	[0.223]	[0.201]	[0.224]	[0.22]	[0.201]	[0.225]	[0.225]
CATBOND	**-4.140*****	**-4.752*****	**-3.81*****	**-3.602*****	**-10.95*****	**-3.044****	**-3.149****
	[1.268]	**[1.559]**	**[1.301]**	**[1.318]**	**[1.928]**	**[1.327]**	**[1.321]**
CAT.HIGHCATEXPOSURE	**-3.956****		**-3.988***	**-5.077*****		**-1.744**	
	[1.997]		**[2.059]**	**[1.961]**		**[2.181]**	
CAT.LOWCATEXPOSURE		**-2.387**					
		[1.805]					
CAT.INDEM			**1.42**			**2.073**	
			[3.497]			**[3.514]**	
CAT.PD(t-1)				**-0.499*****			
				[0.1]			
CAT.LOWREPRICES					**9.209*****		
					[2.444]		
CAT.HIGHREPRICES					**-5.936****		
					[2.422]		
CAT.HIGHCATEXPOSURE.INDEM						**-14.53*****	**-18.87*****
						[4.545]	**[4.57]**
Observations	1,326	1,471	1,326	1,326	1,471	1,326	1,326
Time Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of firms	232	237	232	232	237	232	232
m1-statistic p(value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
m2-statistic p(value)	0.7711	0.772	0.7176	0.5228	0.9159	0.5875	0.5737

Notes: This table reports first-stage Arellano-Bond GMM estimators where CATBOND and the interaction terms are treated as endogenous. The dependent variable, PD, and the explanatory variables are as defined in Table 2. We report robust standard errors in parenthesis. Significance levels are denoted as *** p<0.01, ** p<0.05, * p<0.1.

Table 7. Robustness Checks

	A	B	C	D pre-crisis	E post-crisis
PD(t-1)	0.083***	0.081***	0.085***	0.210***	-0.293***
	[0.027]	[0.027]	[0.027]	[0.031]	[0.054]
ROA	-0.058	-0.05	-0.049	-0.023	0.034
	[0.076]	[0.076]	[0.076]	[0.078]	[0.16]
SIZE	1.884**	1.540**	1.843**	0.226	3.479
	[0.777]	[0.768]	[0.778]	[0.732]	[3.163]
MKTBETA	0.463***	0.458***	0.460***	0.073	0.649**
	[0.102]	[0.102]	[0.102]	[0.094]	[0.256]
HIGHCATEXPOSURE	1.110***	1.115***	1.095***	-0.578*	2.471***
	[0.351]	[0.351]	[0.352]	[0.331]	[0.814]
LOSSRATIO	0.001	0.001	0.001	0.001	0.000
	[0.003]	[0.003]	[0.003]	[0.005]	[0.005]
UWRISK	-0.003	-0.003	-0.003	-0.001	-0.005
	[0.004]	[0.004]	[0.004]	[0.005]	[0.008]
LEVERAGE	-0.04	-0.027	-0.037	-0.03	0.019
	[0.051]	[0.051]	[0.051]	[0.048]	[0.145]
DIVERSIFICATION	0.011	0.032	0.015	-0.05	0.809
	[0.533]	[0.533]	[0.533]	[0.477]	[1.966]
EXPENSERATIO	-0.065	-0.064	-0.069	-0.019	-0.205
	[0.069]	[0.068]	[0.069]	[0.074]	[0.228]
TOBQ	-0.018	-0.015	-0.02	-0.075	1.135
	[0.087]	[0.087]	[0.087]	[0.069]	[0.729]
REPRICES	0.004	0.002	0.003	0.002	-0.058
	[0.007]	[0.007]	[0.007]	[0.007]	[0.04]
GDP	-0.260***	-0.262***	-0.264***	-0.936***	0.089
	[0.087]	[0.087]	[0.087]	[0.338]	[0.279]
GLOBALINSLOSSES	-0.048	-0.118	-0.086	0.338	
	[0.200]	[0.200]	[0.201]	[0.243]	
CATBOND	**-2.525***	**-6.286*****	**-6.323*****	**-3.188****	**-6.326*****
	[1.325]	**[1.483]**	**[1.347]**	**[1.253]**	**[2.34]**
CAT.REINSURANCE	**-6.316*****				
	-2.184				
CAT.USA		**0.057**			
		-2.532			
CAT.SWITZERLAND			**0.486**		
			-4.105		
CAT.HIGHCATEXPOSURE				**-7.486*****	**-6.539***
				-2.208	**-3.36**
Observations	1,471	1,471	1,471	928	398
Time Dummies	Yes	Yes	Yes	Yes	Yes
Number of firms	237	237	237	210	149
m1-statistic p(value)	0.000	0.000	0.000	0.000	0.000
m2-statistic p(value)	0.761	0.8383	0.7784	0.557	0.000

This table reports first-stage Arellano-Bond GMM estimators where CATBOND and the interaction terms are treated as endogenous. Column D presents results for the pre-crisis period (up to 2007) and column E for the post-crisis period (after 2007). The dependent variable, PD, and the explanatory variables are as defined in Table 2. We report robust standard errors in parenthesis. Significance levels are denoted as *** p<0.01, ** p<0.05, * p<0.1.

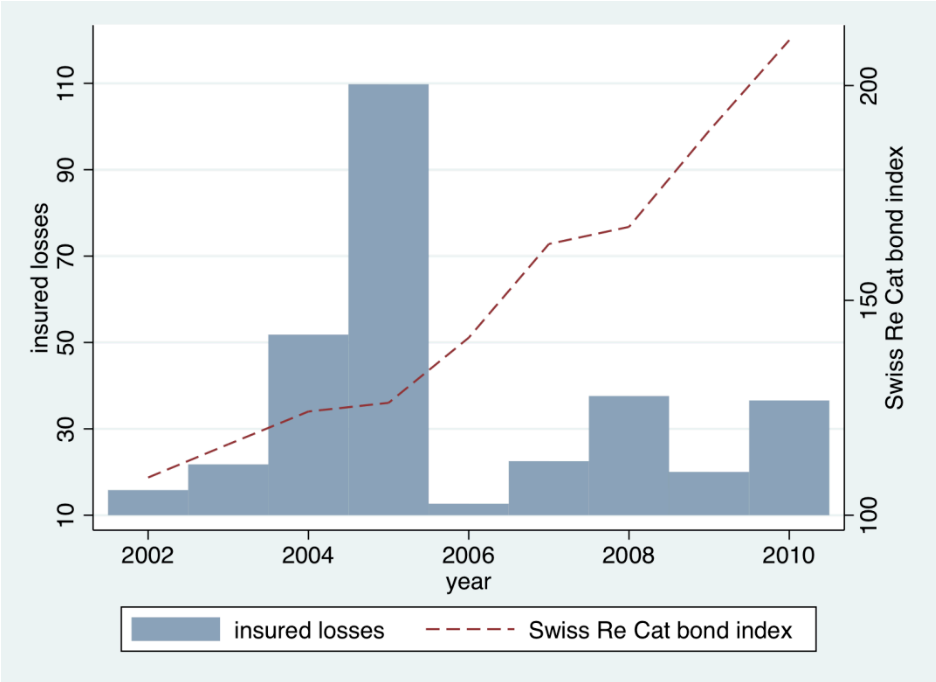
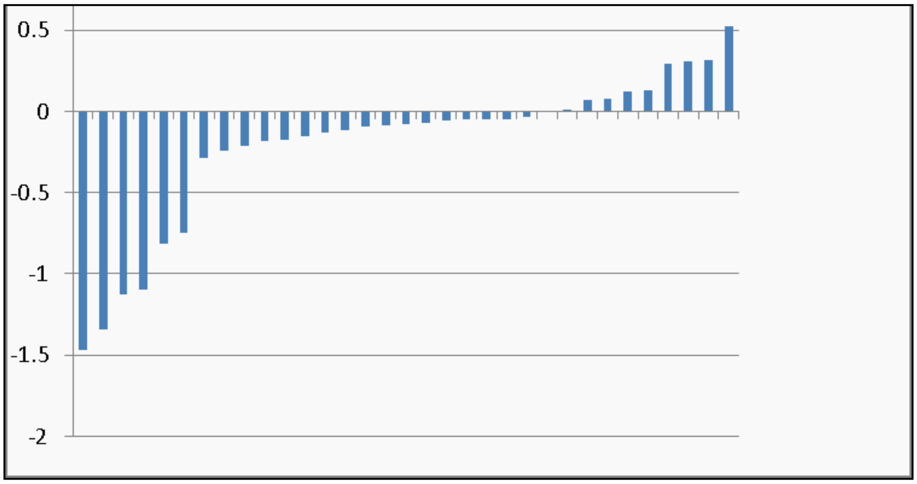


Figure 1. Insured catastrophe losses and Cat bond Returns.
Based on Swiss Re cat bond index which is a total return index using a global market value-weighted basket of natural catastrophe bonds tracked by Swiss Re**.** The total of global insured losses is based from Swiss Re Sigma reports. Sources: Swiss Re *Sigma* & Bloomberg.

Panel A: High catastrophe exposure



Panel B: Low catastrophe exposure

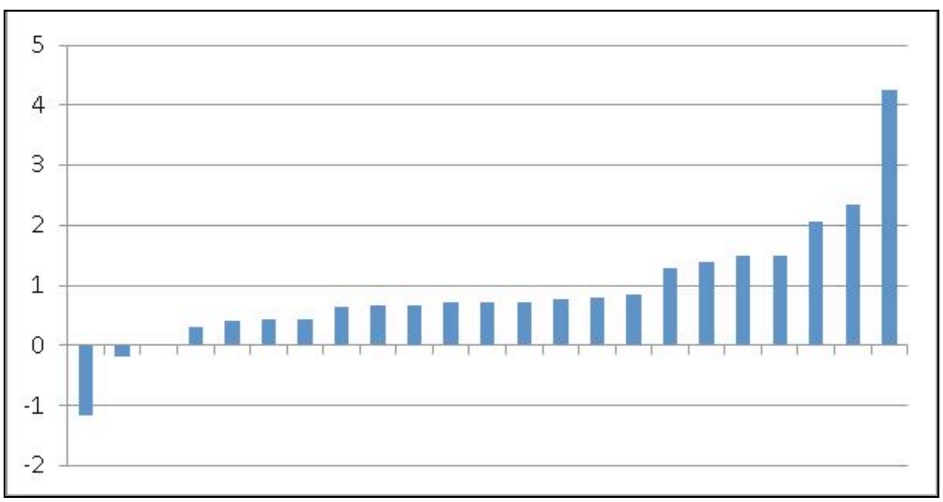


Figure 2. Changes in catastrophe risk exposure. The bars indicate changes in catastrophe exposure (based on firm stock return sensitivity to insured industry catastrophe) one year before the issue relative to one year after the issue of a Cat bond. Panel A shows changes in catastrophe exposure for firms with high catastrophe exposure (located in the top 40% of the distribution of catastrophe exposure) before the issue and Panel B shows firms the same changes for firms in remaining low catastrophe exposure group.