Cat Bonds and Reinsurance Market Dynamics

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This study investigates how catastrophe risk securitization through the use of catastrophe (Cat) bonds influences an insurer's reinsurance usage. The findings reveal that Cat bonds reduce reinsurance usage, particularly during hard underwriting cycles when reinsurance capacity is constrained. In contrast, during soft markets where reinsurance capacity is ample, Cat bonds and reinsurance appear statistically unrelated. Further analysis shows that, under hard market conditions, Cat bond usage decreases internal reinsurance usage but increases external reinsurance usage, with this positive effect on external reinsurance being more pronounced for insurers with high insolvency risk. Furthermore, Cat bond usage reduces reinsurance usage in both catastrophe (Cat) and non-Cat lines of business, suggesting that Cat bonds influence a ceding insurer's risk diversification across both Cat and non-Cat lines.

***Keywords*:** Securitization; Catastrophe risk; Reinsurance; Underwriting cycle; Catastrophe bonds; Internal and external capital allocation; Risk diversification.

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1. Introduction

Managing catastrophe risks associated with large and unexpected losses in the insurance industry has been a focal point of extensive research (e.g., Froot, 2001; Zanjani, 2002; Cummins, Lalonde & Phillips, 2004; Sawada & Shimizutani, 2008; Garmaise & Moskowitz, 2009; Ibragimov, Jaffe, & Walden, 2009, 2011; Collier et al., 2020). Insured losses from catastrophic events have increased significantly since 1970. For instance, Swiss Re reported that natural catastrophes resulted in $117 billion in insured losses in 2023, compared to the previous decade's average of $99 billion.[1] Although reinsurance remains the primary mechanism for transferring catastrophe risk within the insurance sector, valued at $532 billion as of September 30, 2023, there has been rapid growth in securitized catastrophe risk-transfer solutions. These alternatives have expanded from $28 billion in 2011 to $103 billion by September 30, 2023 (Aon Benfield, 2024), highlighting a shift towards innovative capital solutions for managing catastrophe risks.

This paper focuses on catastrophe (Cat) bonds, the most successful securitized risk-transfer solution in terms of outstanding volume, to explore the relationship between catastrophe risk securitization and the reinsurance usage of ceding insurers. Cat bonds, as fully collateralized instruments, pay off when specific, well-defined catastrophic events—such as hurricanes or earthquakes-occur. These bonds effectively transfer catastrophe risk from the insurance industry to the capital markets, representing a key example of the growing convergence between finance and insurance (Froot & Stein, 1998; Cummins et al., 2004; Cummins & Weiss, 2009). For instance, Kleindorfer & Kunreuther (1999) argue that this convergence leads to a more integrated approach to risk management by fostering the development of new financial instruments like Cat bonds and increasing capital availability to mitigate the impact of natural disasters. As of 2023, the total risk capital of outstanding Cat bonds was $43.1 billion, with a record $15.4 billion in new issuance.[2]

As both Cat bonds and reinsurance are both essential mechanisms for transferring

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[1]Swiss Re Institute (2024).
[2]Risk and Insurance Magazine (2024).

catastrophe risk, yet they exhibit several fundamental differences (Cummins & Trainar, 2009): 1) Risk Transfer: Cat bonds facilitate the transfer of catastrophe risks directly from the (re)insurance markets to the securities markets, whereas reinsurance involves the transfer of risk within the (re)insurance markets. 2) Collateralization and Counterparty Risk: Cat bonds are fully collateralized instruments, which significantly mitigates counterparty risk in comparison to traditional reinsurance arrangements. 3) Maturity Structure: Cat bonds typically possess a multiyear maturity structure, in contrast to traditional reinsurance contracts, which are generally limited to a one-year term. 4) Reinstatement Provisions: Traditional reinsurance contracts often include reinstatement provisions, whereas Cat bonds do not. These distinctions underscore the unique characteristics of Cat bonds as financial instruments that enhance risk management strategies for insurers.

The first research question of this paper examines how the utilization of catastrophe (Cat) bonds influences insurers' reliance on traditional reinsurance (Question 1). While numerous theoretical analyses have explored the relationship between Cat bonds and reinsurance, a definitive conclusion remains elusive. Some argue that Cat bonds serve as substitutes for reinsurance (e.g. Froot & Stein, 1998; Cummins & Trainar, 2009; Finken & Laux, 2009; 2012; Subramanian & Wang, 2018). Others suggest that the use of Cat bonds complements reinsurance by benefiting and potentially increasing its usage (Lee & Yu, 2007; Cummins & Trainar, 2009; Härdle & Cabrera, 2010; Lakdawalla & Zanjani, 2012; Zhao et al., 2021).

Cummins and Trainar (2009) emphasize that optimal allocation models for these two products have been underdeveloped in the literature due to their fundamentally different trading mechanisms, risk structures, and contract designs. Chang et al. (2020) address this gap by constructing a two-agent sequential optimization framework to simulate the economics of reinsurance markets. Their theoretical model illustrates how net present value (NPV)-maximizing reinsurers and hedging-cost-minimizing insurers can optimally allocate default-risky catastrophe reinsurance and default-free Cat bonds. They further analyze the parametric impacts of factors such as interest rate risk, financial leverage, basis risk, differential markup, catastrophe arrival intensity, and severity, among other characteristics.

Despite these theoretical insights, empirical evidence on the relationship between Cat bonds and reinsurance remains limited and insufficient to capture the full complexity of their interaction. To address this gap, we investigate the first research question using a sample of U.S. property and casualty (P&C) insurers from 2009 to 2019. A critical aspect of reinsurance decision-making involves determining retention limits (Ali, 2016), which means a ceding insurer's risk tolerance is largely influenced by the amount of risk transferred through Cat bonds. This study measures the extent of risk transfer by examining the outstanding amount of Cat bonds of ceding insurers.

Our empirical results demonstrate that the use of Cat bonds by ceding insurers is significantly and negatively associated with their reliance on traditional reinsurance. Additionally, the underwriting cycle in reinsurance markets plays a critical role in shaping the relationship between Cat bond usage and reinsurance usage. Specifically, ceding insurers that transfer more catastrophe risk through Cat bonds tend to reduce their reinsurance usage to avoid the high costs associated with the hard phase of the reinsurance market. This negative relationship between Cat bonds and reinsurance usage is not observed in the soft market, where reinsurance capacity is abundant and coverage is readily available. Moreover, when a larger proportion of a ceding insurer's Cat bonds near their trigger points or are at risk of default, the insurer increases its use of reinsurance to manage risk. These findings indicate that Cat bonds provide an alternative mechanism for transferring catastrophe risks, influencing the reliance on traditional reinsurance.

An extensive body of literature explores the factors influencing reinsurance decisions (e.g., Mankai & Belgacem, 2016; Park, Xie & Rui, 2019). It is widely recognized that the market condition of reinsurance underwriting cycles plays a crucial role in shaping both the adoption of securitized risk-transfer solutions and insurers' reinsurance decisions

(Winter, 1994; Froot, 2001; Harrington, Niehaus & Yu, 2013). However, the empirical evidence on how underwriting cycles affect insurers' reinsurance usage is limited. Our findings indicate that reinsurance usage among ceding insurers is influenced by reinsurance market cycles, with different determinants emerging in soft versus hard markets.

Reinsurance usage is negatively related to firm size but positively related to performance (ROA) and underwriting risk under both market conditions. During hard markets, insurers with greater geographical diversification exhibit significantly lower reinsurance usage, though this relationship becomes insignificant in soft markets. Additionally, insurers with higher insolvency risk tend to use less reinsurance in hard markets, with the effect diminishing in soft markets. We also find that U.S. insured catastrophe losses significantly increase reinsurance usage in the full sample and soft market subsample, but not in the hard market subsample. Overall, our evidence highlights that the determinants of reinsurance usage vary across different phases of the underwriting cycle.

We conduct various tests to address potential selection and endogeneity concerns in our main results (Question 1). To mitigate selection bias stemming from observable insurer characteristics and potential hidden biases from unobserved factors, we employ propensity score matching (PSM) and the Heckman treatment estimation. Additionally, we use two-stage least squares (2SLS) with instrumental variables and lag the potentially endogenous variable of Cat bonds to account for simultaneity and unobserved omitted variables. Our findings regarding the negative relationship between Cat bonds and reinsurance usage, both in the full sample and the hard market subsample, remain robust after these tests, confirming that our results are not driven by selection or endogeneity concerns.

The second research question explores whether the use of Cat bonds affects internal and external reinsurance differently (Question 2). Internal reinsurance refers to transactions among affiliates within an insurance group, while external reinsurance involves transactions with nonaffiliates. Given the prevalence of insurance groups and the regulatory requirements for information disclosure, many studies analyze internal and external reinsurance usage to examine internal and external capital allocations (Cummins & Weiss, 2016; Koijen & Yogo, 2016; Hepfer, Wilde & Wilson, 2020).

While the relationship between internal and external capital is critical for firms with affiliates (Gertner, Scharfstein & Stein, 1994; Stein, 1997; Billett & Mauer, 2003), the impact of specific external capital transactions, such as Cat bonds, on the internal capital of insurance groups has not been studied. The existing literature typically focuses on the effects of external capital market conditions, such as financial crises, on internal capital allocations. For example, Kuppuswamy & Villalonga (2016) find that the efficiency of internal capital allocation increased significantly during the 2007–2009 financial crisis. Niehaus (2018) shows that internal dividends paid by life insurers to other group entities were more sensitive during the financial crisis than during noncrisis periods. Chiang (2020) also notes that life insurers with bank affiliates experienced higher premium growth rates than other life insurers in 2008.

We extend this research beyond the crisis period, filling the gap by examining how Cat bonds, as a specific type of external capital transaction, impact on internal and external reinsurance usage. The risk transferred through internal reinsurance remains within the insurance group, indicating internal capital allocation, while external reinsurance signifies a genuine transfer of risk. Our findings reveal that Cat bond usage by a ceding insurer has opposing effects on internal and external reinsurance usage during hard reinsurance market conditions but no significant effects in soft markets. Specifically, the use of Cat bonds reduces internal reinsurance while increasing external reinsurance. Therefore, we posit that the utilization of Cat bonds not only affects actual risk transfer through external capital but also influences internal capital allocation within a group via internal reinsurance. Further analysis shows that the positive relationship between Cat bond and external reinsurance usage primarily applies to insurers with high insolvency risk; this relationship does not exist for insurers with low insolvency risk.

Our final research question investigates whether the use of Cat bonds affects reinsurance differently for Cat lines and non-Cat lines (Question 3). The primary insurance market and reinsurance market are two core components of the insurance industry. Berry-Stolzle et al. (2012) distinguish between related and unrelated lines of business diversification in the primary insurance market, finding that information asymmetry and barriers to business growth increase unrelated business line diversification among insurers. However, Cat line-related and unrelated diversification in the reinsurance market has not been thoroughly examined.

We use Cat and non-Cat reinsurance as measures of related and unrelated diversification of catastrophe risk, and analyze the impact of Cat bonds on these two forms of diversification in the reinsurance market. Our findings reveal that Cat bond usage reduces usage for both Cat and non-Cat lines of reinsurance, thereby affecting diversification in both categories of reinsurance business. This evidence expands our understanding of related and unrelated diversification within the reinsurance market.

Overall, the findings from the three research questions provide valuable insights for practitioners and regulators regarding the impact of catastrophe risk securitization on the reinsurance market. P&C insurers offer various policies that cover catastrophe risks, and significant losses from these events threaten insurers' solvency, leading to hard cycles in reinsurance underwriting. These hard cycles can restrict insurers' abilities to manage catastrophic risks effectively through traditional reinsurance mechanisms. Catastrophe risk securitization emerges as an alternative risk-transfer solution, potentially alleviating this dilemma. Therefore, regulatory policies aimed at promoting the development of catastrophe risk securitization should consider the different underwriting cycles present in reinsurance markets. It is crucial for regulators to recognize that when insurers employ catastrophe risk securitization to manage these risks, their reinsurance decisions undergo multiple changes across various dimensions, including internal and external reinsurance usage, as well as diversification related to both Cat line-related and unrelated risks. This paper emphasizes the critical role that Cat bonds play in shaping insurers' approaches to risk management, particularly in response to fluctuating market conditions. As the landscape of catastrophe risk financing evolves, understanding these dynamics will be essential for insurers seeking to optimize their capital allocation and risk transfer strategies.

The remainder of the paper is organized as follows. The next section introduces the data, main specifications, and summary statistics. Section 3 presents the empirical results of three research questions concerning catastrophe risk securitization and the reinsurance usage of ceding insurers. Finally, Section 4 concludes.

2. Data, Main Specifications, and Summary Statistics

2.1 Data

2.1.1 Insurers' Financial Data

Our sample consists of U.S. property and casualty (P&C) insurers from 2009 to 2019. We obtain underwriting and financial data from the National Association of Insurance Commissioners (NAIC) and include only active insurers with no current regulatory actions. Consistent with Mankai & Belgacem (2016) and Park, Xie & Rui (2019), we limit the sample to solvent insurers that report positive values for admitted assets, direct premiums written, loss ratio, surplus, and liability. Following Cummins & Weiss (2016), we conduct our analysis at the group level, as Cat bonds are issued at that level. Financial statement data are aggregated to the group level when affiliated insurers report combined annual statements to the NAIC, otherwise we utilize individual annual statements without losing any data. To mitigate the impact of outliers on our results, we winsorize the financial data at the 1st and 99th percentiles. The final sample is an unbalanced panel consisting of 5,018 insurer-year observations from 742 distinct group or affiliated insurers for 11 years.

2.1.2 Catastrophe Bond Data

We collect data on issue date, sponsors, term, and issue amount for outstanding Cat bonds from various sources, including Artemis, Aon Benfield, and Lane Financial LLC. We then merge the Cat bond data with insurers' financial data from the NAIC using company names and state of domicile. Our sample includes all unmatured Cat bonds issued by U.S. P&C insurers during the period from 2009 to 2019, covering 374 Cat bonds issued between 2004 and 2019.

2.1.3 Catastrophe Losses and Reinsurance Market Data

We obtain data on the year-over-year change in the U.S. property catastrophe Rate-On-Line (ROL) index from Guy Carpenter to measure the underwriting cycle of reinsurance markets. The ROL index represents the ratio of Cat reinsurance premiums to the maximum payout of catastrophe reinsurance contracts, serving as a reflection of Cat reinsurance pricing. Additionally, we collect data on insured losses from catastrophe events between 2009 and 2019 from Property Claim Services (PCS).

2.2 Main Specification

To examine the effect of Cat bonds on reinsurance usage, we estimate the following baseline model:

$$y_{i,t} = \beta_0 + \beta_1 CatBond_{i,t} + \gamma X_{i,t} + \alpha_i + \tau_t + \varepsilon_{it}$$

where the dependent variable $y_{i,t}$ represents the reinsurance usage ratio for insurer i in year t. $CatBond_{i,t}$ denotes the outstanding amount of Cat bonds for ceding insurer i in year t, used to measure the amount of risk transfer through Cat bonds. $X_{i,t}$ is a vector of firm-level and catastrophe loss variables; α_i and τ_t represent firm and year fixed effects; and ε_{it} is an error term. Standard errors are clustered at the firm level. The Appendix provides definitions for all variables.

2.2.1 The Dependent Variable

Reinsurance ratio. In the baseline model, the dependent variable $y_{i,t}$ is the reinsurance ratio (*Reinsurance ratio*) for insurer *i* in year *t*, calculated as the ratio of reinsurance premiums ceded to the sum of the direct premiums written and reinsurance premiums assumed. Ideally, we would like to use the amount of liability covered by reinsurance; however, this information is non-public and unavailable in the NAIC regulatory databases. Therefore, we follow the assumption in reinsurance literature that reinsurance premiums are proportionate to liability coverage. Consequently, we use the ratio of reinsurance premiums ceded to the sum of direct premiums written and reinsurance premiums assumed as a proxy for the reinsurance usage of a ceding insurer (Mankai & Belgacem, 2016).

2.2.2 Main independent variable

Cat bonds. The outstanding amount of Cat bonds ($CatBond_{i,t}$) for insurer *i* in year *t* measures the total amount of catastrophe risk transferred through Cat bonds. This variable offers clearer identification and assessment of the insurer's exposure to catastrophic events and provides a more precise measure of catastrophe risk transfer through securitization for an insurer in a given year than a binary variable that simply indicates whether Cat bonds were issued. For example, since most Cat bonds have multiyear maturities, a ceding insurer may have outstanding Cat bonds without issuing new ones in a given year. In such cases, a dummy variable representing the issuance of Cat bonds may not adequately capture the overall catastrophe risk transfer through securitization. We calculate $CatBond_{i,t}$ based on the issue date and term, and deduct the issue amount of a triggered (defaulted) Cat bond from the total outstanding amount of Cat bonds for an insurer after the trigger (default) date. Additionally, in cases of mergers and acquisitions (M&As), we add the unmatured Cat bond amount of the merged or acquired insurer to the Cat bond amount of the acquiring insurer (or the newly created legal entity).

2.2.3 Control Variables

We include a vector of firm-level and catastrophe loss control variables, "*X*," in the baseline model.[3] These variables are:

1) Firm size. Firm size affects the reinsurance usage, with studies documenting a negative relationship between firm size and reinsurance usage (Cummins & Weiss, 2016). Smaller firms tend to rely more on reinsurance due to lower economies of scale and scope in risk management (Mankai & Belgacem, 2016). We measure firm size using the log of the ceding insurer's admitted assets (*LogAsset*).

2) Performance. High profitability insurers might usage less reinsurance due to sufficient internal funds, or they might usage more reinsurance to mitigate higher risks associated with better financial performance (Mankai & Belgacem, 2016). We measure profitability using return on assets (*ROA*).

3) Risk diversification. Insurers traditionally diversify risks internally across different lines of business and geographical regions. When diversification is insufficient, primary insurers may purchase reinsurance to transfer excessive risk (Cummins & Trainar, 2009). Previous studies show that diversification across lines of business and geographical regions reduces reinsurance usage. We include a Herfindahl index for lines of business (*LOB_herf*), based on direct premiums written in each line of business, and a Herfindahl index for geographical regions (*GEO_herf*), based on direct premiums written across geographic areas, to control for the effects of risk diversification on reinsurance usage.

4) Insolvency risk. Insolvency risk significantly influences reinsurance usage. Cummins & Weiss (2016) find that insurers with higher leverage (liabilities/total assets) have a greater need for reinsurance. Conversely, reinsurers often charge higher premiums to

[3] The NAIC exclusively reports insurers' organizational forms using individual annual statements, making the organizational forms inapplicable for combined annual statements within the NAIC framework. As a result, we have excluded the variable of organizational forms from our empirical analysis. Additionally, we have included firm fixed effects in our empirical analysis to control for the time-invariant effects of organizational form.

insurers with high insolvency risk, reducing their usage for reinsurance (Park, Xie & Rui, 2019). We measure insolvency risk using the ratio of liabilities to total assets (*Leverage*).

5) **Underwriting risk.** Reinsurance usage is influenced by the underwriting risk of ceding insurers. We include three variables to measure this risk: *Business/Surplus*, *LossRatio*, and *LossVolatility*. Insurers that write more business relative to their surplus often face an insufficient surplus and thus increase their reinsurance usage, as reinsurance serves as a substitute for surplus (Garven & Lamm-Tennant, 2003). However, Mankai & Belgacem (2016) find that increased risk-taking due to higher business relative to surplus has no significant impact on reinsurance usage. We measure underwriting risk using the ratio of direct business written to surplus (*Business/Surplus*). Additionally, we follow Mankai & Belgacem (2016) and Che, Liebenberg & Lynch (2021) by including the loss ratio (*LossRatio*) and the standard deviation of loss ratios over the past five years (*LossVolatility*) as alternative measures of underwriting risk.

6) **Long-tail risk.** Insurers that underwrite long-tail risks generate more investable funds per dollar of premiums, potentially increasing their usage for reinsurance (Garven & Lamm-Tennant, 2003). However, Park, Xie & Rui (2019) find no evidence that long-tail risks are related to reinsurance usage. We use the proportion of direct premiums written in long-tail liness to total premiums (*Long_tail*) to control for the potential effect of long-tail risks on reinsurance usage. Long-tail lines include farm multiperil, homeowners' multiperil, commercial multiperil, medical malpractice, workers' compensation, product liability, automobile liability, and "other" liability.

7) **Catastrophe risk.** Insurers often rely on reinsurance to transfer catastrophe risk. We measure catastrophe risk exposure using the ratio of direct premiums written in catastrophe lines to total premiums (*CatRisk*). Born & Klimaszewski-Blettner (2013) categorize homeowners, fire, allied, and commercial multiperil lines as catastrophe lines, while Park, Xie & Rui (2019) include homeowners, farm owners, auto physical damage, commercial multiperil, and inland marine. Mankai & Belgacem (2016) consider

earthquake as a catastrophe line of business. We adopt a broad definition of catastrophe lines, including homeowners, fire, allied, commercial multiperil, earthquake, farm owners, auto physical damage, and inland marine. Additionally, we include U.S. insured losses from catastrophe events (*US_CatLoss*) in our regression models to capture the impact of catastrophe losses on reinsurance usage.

2.3 Summary Statistics

Table 1, Panel A presents summary statistics for reinsurance, Cat bonds, firm characteristics, and catastrophe loss variables. The mean and standard deviation of the reinsurance ratio are 0.275 and 0.262, respectively. This mean value indicates that, on average, sample firms ceded 27.5% of their direct premiums written and reinsurance premiums assumed to other (re)insurers. Regarding the total amount of outstanding Cat bonds (*CatBond*), the mean is 0.031 ($Billion), suggesting that, on average, an insurer transfers $31 million in catastrophe risk capital through Cat bonds per year. The summary statistics in Panel A indicate that our sample is comparable to those used in other studies, such as Mankai & Belgacem (2016) and Park, Xie & Rui (2019).

(Insert Table 1 about here)

We divide the sample into two groups: the Cat bond group and the reinsurance group. The Cat bond group consists of insurers that use Cat bonds to manage catastrophe risk (*CatBond > 0*), while the reinsurance group includes insurers that do not use Cat bonds (*CatBond = 0*). Panel B of Table 1 reports the t-tests for the differences in sample means between the two groups. The average reinsurance ratio is slightly higher in the Cat bond group (0.288) compared to the reinsurance group (0.275), but this difference is not statistically significant.

In the Cat bond group, the mean value of *CatBond* is 0.683, indicating that, on average, Cat bond insurers transfer $683 million in catastrophe risk through Cat bonds per year. Compared to the reinsurance group, Cat bond insurers tend to have larger firm sizes (*LogAsset*), better performance (*ROA*), more risk diversification (*GEO_herf* and *LOB_herf*), higher insolvency risk (*Leverage*) and greater catastrophe risk exposure (*CatRisk*). However, they have lower underwriting risk (*Business/Surplus* and *LossVolatility*) and less exposure to long-tail risks (*Long_tail*).

3. Empirical Results

In this section, we investigate the impact of Cat bond usage on reinsurance usage and explore the factors influencing reinsurance usage across different phases of underwriting cycle in reinsurance markets. We also analyze the effects of Cat bond usage on internal and external reinsurance usage, as well as its impact on Cat-related and non-Cat-related diversification within the reinsurance market.

3.1 Question 1: Does the Use of Cat Bonds Influence an Insurer's Reinsurance Usage?

3.1.1 Cat bonds are negatively related to reinsurance usage in the full sample

The theoretical models models discussed earlier provide mixed predictions regarding whether Cat bonds increase or decrease an insurer's reinsurance usage. To empirically test this relationship, we use the baseline model to examine the influence of Cat bond on reinsurance usage. Columns (1) and (2) of Table 2 present the results for the full sample. In column (1), we run a parsimonious model without control variables, while in column (2), we include the baseline model with firm characteristics and catastrophe loss controls. Both models incorporate year-fixed and firm-fixed effects to account for potential time trends and time-invariant factors that may affect an insurer's reinsurance usage.

(Insert Table 2 about here)

The coefficients on *CatBond* are negative (-0.036, -0.039) and significant at 1% level in columns (1) and (2) of Table 2, susggesting that Cat bonds and reinsurance are alternative risk transfer instruments. The coefficient of *CatBond* in column (2) indicates that, all else being equal, a one-standard-deviation increases in *CatBond* (0.200) is associated with a change in reinsurance usage (*Reinsurance ratio*) of -0.039*0.200=-0.008. It represents a 2.909% decrease from the mean value of *Reinsurance ratio* (0.275). Additionally, the empirical results in column (2) reveal several significant determinants of reinsurance usage in the full sample, including firm size (*LogAsset*), performance (*ROA*), insolvency risk (*Leverage*), underwriting risk (*Business/Surplus* and *LossRatio*), and U.S. insured losses of catastrophe events (*US_CatLoss*).

3.1.2 The Relationship between Cat Bond Usage and Reinsurance Usage varies with the Underwriting Cycle

Froot (2001) and Cummins & Trainar (2009) conjecture that market conditions of reinsurance underwriting cycle influence the relationship between Cat bonds and reinsurance. However, the literature lacks empirical evidence on the effect of the underwriting cycle on this relationship. To test this conjecture, we divide the full sample into hard and soft market subsamples based on changes in U.S. property catastrophe Rate-On-Line (ROL) index. The U.S. property catastrophe ROL index, maintained by Guy Carpenter since 1990, tracks movements in reinsurance rates for brokered excess of loss placements. Traditional reinsurance contracts typically last one year; thus, a positive change in the ROL index indicates rising catastrophe reinsurance prices relative to the previous year, suggesting a decrease in available reinsurance capacity, which we classify as a hard market. Conversely, a negative change indicates a soft market.

Figure 1 illustrates changes in the U.S. ROL index alongside U.S. insured losses from catastrophic events between 2007 and 2009. Within our study period (2009-2019), years identified as hard markets include 2009, 2012, 2018, and 2019, following significant increases in insured catastrophe losses. Major catastrophic events such as Hurricane Ike in 2008, Hurricane Irene in 2011, Hurricane Sandy in 2012, and Hurricanes Maria and Irma in 2017 contributed to these hard market conditions.

(Insert Figure 1 about here)

The results in columns (3) through (6) of Table 2 show that the negative and significant coefficients on *CatBond* are present in the hard market subsample (columns (3) and (4)) but not in the soft market (columns (5) and (6)). The coefficients for *CatBond* are -0.056 or -0.058 (significant at 1% level) in the hard market but insignificant in the soft market. This indicates that Cat bonds do not compete with reinsurance during soft market phases, suggesting that the relationship between Cat bond and reinsurance usage depends on the reinsurance market's underwriting cycle.

Columns (3) through (6) of Table 2 also report other determinants of reinsurance usage in the hard and soft markets. Firm size (*LogAsset*), performance (*ROA*) and underwriting risk (*Business/Surplus* and *LossRatio*) influence reinsurance usage in both hard and soft markets, with the coefficients showing no notable difference between the two. However, the coefficient for geographical diversification (*GEO_herf*), is significant and negative in the hard market but insignificant in the soft market, indicating that geographically diversified insurers reduce reinsurance usage during hard markets. The coefficients for insolvency risk (*Leverage*) are -0.261 (significant at 1%) in the hard market and -0.131 (significant at 10%) in the soft market. This suggests that the effect of insolvency risk on reinsurance usage is nearly double in the hard market compared to the soft market. Insurers with higher insolvency risk use significantly less reinsurance during hard market conditions due to restricted reinsurance capacity. Additionally, the coefficient on U.S. insured catastrophe losses (*US_CatLoss*) is significant and positive in the full sample and the soft market but is insignificant in the hard market. This could be due to the high cost and limited supply of reinsurance in the hard market, which overshadows the influence of U.S. insured Cat losses on reinsurance usage.

3.1.3 Cat Bonds at Risk are Positively related to Reinsurance Usage

In this section, we examine the relationship between the riskiness of an insurer's outstanding Cat bonds and its reinsurance usage. When a Cat bond approaches its trigger or default point, it is considered "at risk." We use the amount of Cat bonds at risk from the total outstanding Cat bonds for insurer *i* in year *t* (*CatBond@risk*) as a proxy for the riskiness of an insurer's *CatBond*. Insurers with more Cat bonds at risk are typically viewed as high-risk Cat bond sponsors by investors, who then demand a higher return (or higher bond spread) for these Cat bonds. As a result, these insurers may increase their use of reinsurance to mitigate the higher cost associated with Cat bond usage.

Our data reveal that it can take anywhere from a few months to three years for a sponsor to determine the loss amount of a triggered or defaulted Cat bond. In our sample, 29 Cat bonds are classified as at risk, with the average amount of Cat bonds at risk for a Cat bond insurer being $15.781 million per year. We substitute "*CatBond*" in the baseline model with "*CatBond@risk.*" If the riskiness of an insurer's Cat bonds (as measured by *CatBond@risk*) is positively related to reinsurance usage, it suggests that insurers use more reinsurance rather than Cat bonds to avoid the higher costs associated with having bonds at risk.

(Insert Table 3 about here)

The results of columns (1), (3), and (4) in Table 3 indicate that *CatBond@risk* has a significant and positive effect on the reinsurance ratio, suggesting that the increased riskiness of an insurer's Cat bonds leads to higher reinsurance usage. Furthermore, the positive and significant coefficients for *CatBond@risk* are observed only in the hard market (columns (3) and (4)), suggesting that reinsurance usage is unaffected by the riskiness of Cat bonds during soft market conditions.

3.1.4 Addressing Endogeneity Concerns

Our analysis of the relation between Cat bonds and reinsurance usage may be subject to endogeneity issues arising from self-selection, simultaneity, or unobserved omitted variables. To address these concerns, we implement several methods: Propensity Score Matching (PSM) and the Heckman Treatment Estimate help mitigate selection bias caused by observable insurer characteristics and potential hidden biases due to the omission of unobserved factors. We employ Two-Stage Least Squares (2SLS) with instrumental variables to address endogeneity concerns related to simultaneity and omitted variables. Additionally, we lag the potentially endogenous variable, Cat bonds, to further reduce endogeneity issues. These robustness checks strengthen our findings and ensure that the observed relationship between Cat bonds and reinsurance usage is not driven by endogeneity concerns.

1) Propensity Score Matching (PSM)

The Cat bond group (*CatBond* > 0) and the reinsurance group (*CatBond* = 0) differ across several dimensions. For instance, Panel B of Table 1 shows that firm size, risk diversification, insolvency risk, catastrophe risk exposure, underwriting, and long-tail risks are significantly different between the two groups. These differences might introduce sample bias, leading to a relationship between Cat bonds and reinsurance that merely reflects the underlying differences between the groups rather than a true causal relationship.

To address this self-selection concern, we use propensity score matching (PSM) to create a set of balanced covariates between Cat bond insurers and reinsurance insurers, thereby minimizing the differences between the two groups and making them more comparable. We match each Cat bond group insurer with a reinsurance group insurer based on a series of firm characteristics, including firm size (*LogAsset*), performance (*ROA*), diversification (*GEO_herf* and *LOB_herf*), insolvency risk (*Leverage*), underwriting risk (*Business/Surplus*, *LossRatio*, and *LossVolatility*), long-tail risks (*Long_tail*), and catastrophe risks (*CatRisk*). Following Rosenbaum & Rubin (1985), we run a logit model to generate a propensity score, which represents the predicted probability of an insurer belonging to the Cat bond group. We then perform one-to-one matching with noreplacement, using the nearest neighbor propensity score to select matched reinsurance group insurers. This approach helps ensure that any observed relationship between Cat bonds and reinsurance usage is not driven by differences in firm characteristics but rather reflects the underlying dynamics between the two.

(Insert Table 4 about here)

Panel A of Table 4 presents the t-tests of differences in firm characteristics between the Cat bond group and the matched control group. All firm characteristics become statistically insignificant between the two groups, indicating that Cat bond group insurers and the matched non-Cat bond (reinsurance group) insurers have balanced covariates. This suggests that the propensity score matching process successfully reduced the differences in firm characteristics between the groups.

Next, we estimate the baseline model using the matched sample. Consistent with the results from the unmatched sample in Table 2, Panel B of Table 4 shows that that the coefficients on *CatBond* are significantly negative in both the full sample and the hard market subsample, but not in the soft market subsample. This finding supports the conclusion that Cat bonds decreases reinsurance usage during hard market conditions of reinsurance underwriting.

2) Heckman Treatment Estimate

While propensity score matching (PSM) helps address observable differences between the Cat bond group and the reinsurance group, it cannot fully address potential hidden biases stemming from self-selection. To further mitigate concerns that the decision to issue Cat bonds is not random, we apply the Heckman treatment estimate. This method allows us to account for potential selection bias that may arise from unobserved factors influencing both the issuance of Cat bonds and reinsurance usage.

The Heckman treatment model involves two stages. In the first stage (the selection equation), we estimate the probability of an insurer using Cat bonds. In the second stage, we assess the effect of of Cat bonds (*CatBond*) on reinsurance usage. The inverse Mills ratio (*IMR*), estimated from the first-stage model, is inccluded as a control in the second-stage model to adjust for potential selection bias.

For the Heckman model to be effective, it requires one or more variables, known as exclusion restrictions, in the first stage that do not appear in the second stage. Previous studies (e.g., Zhao & Yu, 2020) find that the BB-rated corporate bond spread significantly influences the issuance cost of Cat bonds because Cat bond investors perceive that Cat bonds and corporate bonds with the same rating carry similar risks. At the same time, the corporate bond spread is typically unrelated to reinsurance usage. Since most Cat bonds are rated BB, the BB-rated corporate bond spread (*BBbond*) can serve as an exclusion restriction that affects the probability of an insurer using Cat bonds (first stage) but does not directly influence reinsurance usage (second stage). Additionally, we include the control variables from the baseline model in the selection equation, as these factors may also affect an insurer's decision to issue Cat bonds.

(Insert Table 5 about here)

The results of the selection equation (first stage) in column (1) of Table 5 show that the coefficient of *BBbond* is significant and negative. This finding supports the idea that investors perceive Cat bonds and corporate bonds with the same rating to carry identical risks, leading to a lower probability of an insurer using Cat bonds when the corporate bond spread is higher due to increased issuance costs. To further validate *BBbond* as an exclusion restriction, we add it to the baseline model, and the unreported results indicate that *BBbond* is indeed unrelated to reinsurance usage. Therefore, the exclusion restriction in our study is effective.

The results of the second-stage model, presented in columns (2)–(4) of Table 5, control for potential selection bias using the inverse Mills ratio (IMR). The coefficient on the inverse Mills ratio is statistically insignificant, suggesting that self-selection bias does not pose a concern for our analyses. These results in columns (2)-(4) are consistent with our main findings: Cat bonds (*CatBond*) have significant and negative effects on reinsurance usage in the full sample and the hard market subsample, but not in the soft market subsample. This confirms that our findings are robust to concerns about selection bias.

3) Lagging the *CatBond* variable

To further address endogeneity concerns related to the simultaneity of reinsurance and Cat bond decisions by ceding insurers, we introduce a one-period lag in the outstanding Cat bonds variable, *LagCatBond*, in the baseline model. This approach allows us to examine the relationship between reinsurance usage and lagged Cat bonds, helping to reduce simultaneity bias.

The results, presented in Table 6, support our main findings from Table 2. The coefficients for *LagCatBond* are negative and significant at the 1% level in both the full sample and the hard market subsample, while they remain insignificant in the soft market subsample. These findings confirm that the negative effect of Cat bonds on reinsurance usage is robust, even when accounting for potential simultaneity.

(Insert Table 6 about here)

4) Two-Stage Least Squares (2SLS)

The variable Cat bonds (*CatBond*) could be endogenous due to unobservable omitted variables and/or feedback loops between Cat bonds and reinsurance usage. Hence, we use 2SLS to test whether our main results are robust to endogeneity.

The effectiveness of 2SLS depends on identifying a valid instrument that is related to *CatBond* in the first-stage model but uncorrelated with the error term of the second-stage regression of reinsurance usage. To achieve this, we leverage the fully collateralized structure of Cat bonds by decomposing *CatBond* to construct the instrument (*IV*) using the following two setps. In the first step, we deduct the new issue amount of Cat bonds in year *t* from the outstanding Cat bonds in year *t*. This helps eliminate the effects of joint decisions between the issuance of new Cat bonds and reinsurance usage within the same year. Then, we conduct the second that further deducts the amount of Cat bonds that become "at risk" for an insurer *i* in year *t* to calculate the instrument (*IV*). This additional step reduces the influence of omitted risk variables on the simultaneity of Cat bonds and reinsurance usage. our instrument (*IV*) satisfies the relevance condition as it is part of *CatBond*, and its fully collateralized nature, combined with the adjustments for new issuances and bonds at risk, ensures the exogeneity condition. Figure 2 illustrates the construction of instrumental variables.

(Insert Figure 2 about here)

(Insert Table 7 about here)

Columns (1), (3) and (5) of Table 7 presents estimates of the first-stage equations, where the dependent variable is *CatBond*. The results indicate that the coefficients of *IV* are highly statistically significant in first-stage equations. Columns (2), (4) and (6) report the second-stage results, where *CatBond* is replaced by the fitted value derived from the first stage ($\widehat{CatBond}$). Consistent with the results reported in Table 2, the coefficients for $\widehat{CatBond}$ are significantly negative in the full sample and the hard market subsample, but not in the soft market subsample. Therefore, our findings regarding the relationship between Cat bonds and reinsurance usage remain robust, even when addressing potential endogeneity bias.

3.2 Question 2: Does Cat Bond Affect Internal and External Reinsurance Differently?

3.2.1 Cat bonds decrease internal reinsurance usage but increase external reinsurance usage in the full sample and the hard market subsample

To investigate the differential impact of Cat bond usage on the use of internal and external reinsurance, we follow the literature by using internal and external reinsurance ratios (*In-Rein* and *Ex-Rein*) as dependent variables (Cummins & Weiss, 2016). The internal reinsurance ratio (*In-Rein*) is defined as the ratio of reinsurance premiums ceded to affiliates to the sum of direct premiums written and total reinsurance premiums assumed. Similarly, the external reinsurance ratio (*Ex-Rein*) is the ratio of reinsurance premiums ceded to nonaffiliates to the sum of direct premiums written and total reinsurance premiums assumed.

(Insert Table 8 about here)

Columns (1) and (2) of Table 8 show that Cat bonds usage (*CatBond*) has significant and opposite effects on internal and external reinsurance usage in the full sample. Specifically, *CatBond* decreases internal reinsurance usage (*In-Rein*) while increasing external reinsurance usage (*Ex-Rein*). These significant effects are observed only in the hard market subsample (columns (3) and (4)), but not in the soft market subsample (columns (5) and (6)). Although the results in Table 2 suggest that Cat bonds and overall reinsurance usage are altrenative, Table 8 reveals that the use of Cat bonds decreases internal reinsurance usage while increasing external reinsurance usage. This contrasting relationship holds true for both the full sample and the hard market subsample, but not for the soft market subsample. In the hard market, a one-standard-deviation increase in *CatBond* (0.214) is associated with a change in external reinsurance usage (*Ex-Rein*) by 0.024*0.214=0.005, representing an 2.647% (0.005/0.194) increase from the mean value of *Ex-Rein*. Similarly, a one-standard-deviation increase in *CatBond* results in a decrease of internal reinsurance usage (*In-Rein*) by 23.112% ((-0.081*0.214)/0.075).

3.2.2 Cat Bonds Increase External reinsurance Usage in the Hard Market, and the Positive Effect is Mainly Driven by High-Leverage Insurers

Next, we explore why Cat bonds (*CatBond*) increase the external reinsurance usage (*Ex-Rein*) in both the full sample and hard market subsample. Lee & Yu (2007) and Lakdawalla & Zanjani (2012) theoretically predict that issuing Cat bonds insurers can help insurers reduce insolvency risk, which lead to an increase in reinsurance usage. To measure the insolvency risk, we follow the literature and use leverage (liabilities/total assets) (Cummins & Weiss (2016); Park, Xie & Rui (2019)).

(Insert Table 9 about here)

To further investigate this relationship, we add an interaction term between *CatBond* and *Leverage* to examine how insolvency risk influences the relationship between Cat bonds and external reinsurance usage. After controlling for this interaction, Table 9 shows that the coefficients for *CatBond* become insignificant in the full sample (columns (1) and

(2)). However, in the hard market subsample, the coefficient for *CatBond* becomes significantly negative, and the coefficient for the interaction term (*CatBond* * *Leverage*) is significantly positive. These results imply that, other things being equal, the effect of *CatBond* on external reinsurance usage is calculated as -0.182+0.297**Leverage*. When an insurer's leverage exceeds 0.616 (0.183/0.297), the effect Cat bonds on external reinsurance usage becomes significantly positive. This suggests that the use of Cat bonds increases external reinsurance usage for high-leverage insurers, while for low-leverage insurers, the relationship between Cat bonds and external reinsurance remains significantly negative.[4]

We further test an alternative measure of high insolvency risk, using a dummy variable (*HighLeverage*) that equals one if an insurer's leverage is in the top 25%, and zero otherwise. We then include an interaction term (*CatBond* **HighLeverage*) in the regression. Consistent with the results using continuous leverage, column (3) shows that the positive relationship between Cat bonds and external reinsurance usage exists only for high-leverage insurers. For low-leverage insurers, a substitution relationship between Cat bonds and external reinsurance usage persists in the hard market.

These findings suggest that the relationship between Cat bonds and external reinsurance usage depends on the insurer's insolvency risk. We infer that external reinsurance is more sensitive to an insurer's insolvency risk than internal reinsurance. High insolvency risk insurers using Cat bonds to transfer risk may reduce concerns about counterparty risk in external reinsurance transactions, which could explain why high insolvency risk insurers see an increase in external reinsurance usage alongside their use of Cat bonds, rather than relying on internal reinsurance.

3.3 Question 3: Does Cat Bond Usage Decrease Cat line and Non-Cat Line of Reinsurance Differently?

[4] Table 1 shows that the mean value of insurers' leverage (*Leverage*) is 0.566 in the full sample.

We examine the impacts of Cat bonds on related and unrelated diversification of catastrophe risk in the reinsurance market by using Cat and non-Cat reinsurance as measures of these two types of diversification. First, we identify catastrophe lines of business for insurers and calculate the Cat reinsurance usage (*Cat_Rein*) and non-Cat reinsurance usage (*non-Cat Rein*) ratios.[5] The variable *Cat_Rein* represents the ratio of reinsurance premiums ceded in generalized Cat lines to the sum of direct premiums written and reinsurance premiums assumed in these lines. The generalized Cat lines of business include homeowners, fire, allied, commercial multiple peril, earthquake, farm owners, auto physical damage, and inland marine. Similarly, we calculate *non-Cat Rein* based on non-Cat lines of business and use *Cat_Rein* and *non-Cat Rein* as dependent variables.

(Insert Table 10 about here)

For Cat reinsurance usage (*Cat_Rein*), Pane A of Table 10 shows that the coefficient on *CatBond* is significant and negative in the full sample (column (1)) and the hard market subsample (column (2)), but insignificant in the soft market subsample (column (3)). The results reveal that Cat bonds act as an alternative to Cat reinsurance for Cat lines of business, especially during hard markets. The coefficient of *CatBond* in column (2) of Panel A indicates that, on average, a one-standard-deviation increase in *CatBond* (0.214) change in Cat reinsurance usage (*Cat_Rein*) by -0.062*0.214=-0.013 in the hard market. This represents a 5.603% (-0.013/0.232) decrease from the mean value of *Cat_Rein*.

Panel B of Table 10 illustrates the effects of Cat bonds on non-Cat reinsurance. Columns (1) and (2) indicate that although Cat bonds and non-Cat reinsurance cover different lines of business, Cat bonds still act as alternative for non-Cat reinsurance in both the full sample and the hard market subsample. In the hard market, a one-standard-

[5] While Cat reinsurance contracts are typically non-proportional, we refrain from utilizing the non-proportional reinsurance ratio as a measure of Cat reinsurance usage due to the lack of corresponding direct premiums reported by NAIC.

deviation increase in *CatBond* (0.214) change in non-Cat reinsurance usage (*non-Cat Rein*) by -0.040*0.214=-0.009, representing a 6.767% (-0.009/0.133) decrease from the mean value of *non-Cat Rein*. This suggests that the use of Cat bonds by a ceding insurer affects its diversification across both Cat and non-Cat lines of business in the reinsurance market.

4. Conclusions

This study examines the role of Cat bonds in catastrophe risk securitization within the reinsurance market, using a sample of U.S. property-casualty insurers from 2009 to 2019. We explored the relationship between an insurer's use of Cat bonds and its reinsurance usage across different phases of the reinsurance market's underwriting cycle. Our findings indicate that Cat bonds is alternative for reinsurance in the full sample, with the significant negative relationship manifesting only during hard reinsurance market conditions, not in soft markets. Ceding insurers use Cat bonds to transfer more catastrophe risk and reduce their reliance on reinsurance to avoid the high costs associated with reinsurance during hard market phases. This relationship remains robust even when accounting for potential biases due to self-selection, simultaneity, or unobservable omitted variables.

However, we also find that insurers with more Cat bonds at risk tend to increase their usage of traditional reinsurance. Additionally, we observe that geographical diversification and insolvency risk are significantly and negatively related to reinsurance usage in hard markets. However, geographical diversification becomes insignificant, and the effect of insolvency risk is reduced by half with lower significance in soft markets. This suggests that insurers with high geographical diversification can avoid the high costs of reinsurance during hard markets, while high-insolvency-risk insurers face more severe constraints on reinsurance usage in hard markets due to limited reinsurance supply.

When decomposing total reinsurance usage into internal and external reinsurance, we find that Cat bonds have a significantly positive effect on external reinsurance usage but a negative effect on internal reinsurance usage during hard market conditions. In soft markets, Cat bonds have no significant relationship with either internal or external reinsurance usage. Further analysis reveals that the positive effect on external reinsurance usage is concentrated among high-leverage insurers. External reinsurance is more sensitive to an insurer’s insolvency risk than internal reinsurance, and high-insolvency-risk insurers can reduce counterparty risk concerns in external reinsurance transactions by using Cat bonds to transfer risk.

Although Cat and non-Cat reinsurance cover different lines of business, our results show that Cat bonds substitute for both Cat and non-Cat reinsurance usage in the full sample and hard market subsample. The use of Cat bonds to transfer catastrophe risk decreases the use of both Cat and non-Cat reinsurance in hard markets, indicating that Cat bonds affect a ceding insurer’s risk diversification across both Cat and non-Cat lines of business in the reinsurance market.

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Figure 1: U.S. ROL Index Changes and U.S. Insured Losses from Catastrophic Events

This figure shows changes in U.S. property catastrophe Rate-On-Line (ROL) index and U.S. insured losses from catastrophic events spanning from 2007 to 2009. The U.S. property catastrophe ROL index is the proprietary index of US property catastrophe reinsurance Rate-on-Line movements, on brokered excess of loss placements, that has been maintained by Guy Carpenter since 1990.

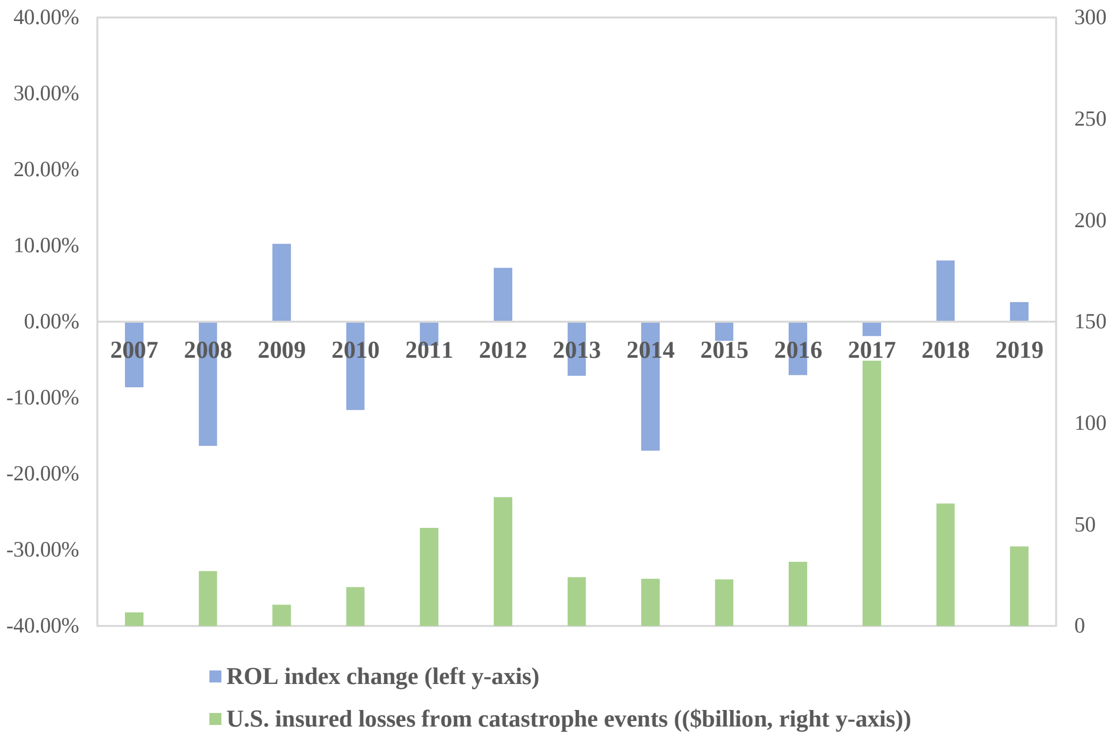

Figure 2: Construction of Instrumental Variables

This figure shows the construction of two instrumental variables (*IV*). Instrument (*IV*) equals that outstanding Cat bonds in year *t* deduct the new issue amount of Cat bonds and the amount of Cat bonds that become at risk for an insurer *i* in year *t*. It rules out the effects of joint decisions between the issuance of new Cat bonds and reinsurance usage in year *t*, and avoid the effects of omitted risk variables on the trigger or default for a Cat bond and simultaneity.

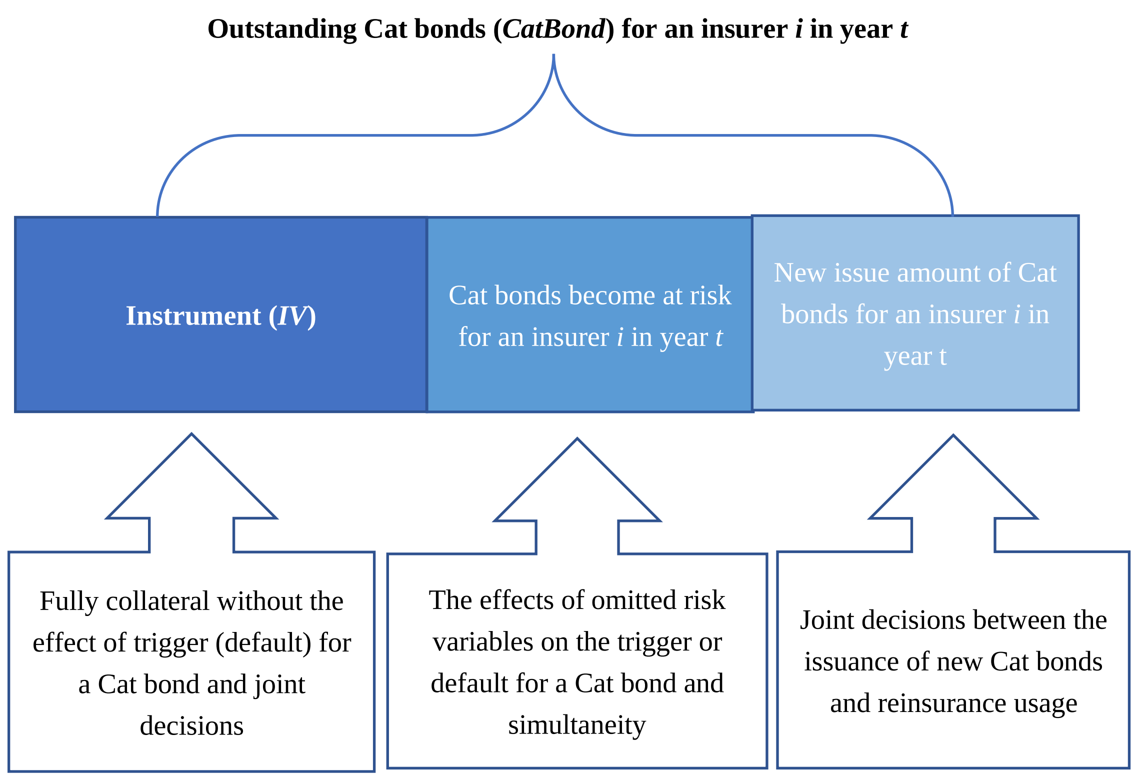

Table 1: Summary Statistics

This table reports the summary statistics of key variables for all sample P&C insurers in Panel A from 2009 to 2019. The detailed variable definitions are listed in the Appendix. Panel B shows the differences in the means of each variable between Cat bond group (*CatBond >0*) and reinsurance group (*CatBond=0*). *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels.

Panel A: Full Sample

	N	Mean	SD	Min	Max
Reinsurance ratio	5,018	0.275	0.262	0.000	0.984
CatBond ($Billion)	5,018	0.031	0.200	0.000	3.750
LogAsset	5,018	19.568	2.148	14.005	24.441
ROA	5,018	0.017	0.049	-0.206	0.172
GEO_herf	5,018	0.465	0.380	0.040	1.000
LOB_herf	5,018	0.503	0.307	0.115	1.000
Leverage	5,018	0.566	0.168	0.022	0.914
Business/Surplus	5,018	1.509	1.526	0.008	9.865
LossRatio	5,018	0.709	0.265	0.054	2.179
LossVolatility	5,018	0.161	0.385	0.012	3.368
Long_tail	5,018	0.686	0.303	0.000	1.000
CatRisk	5,018	0.449	0.353	0.000	1.000
US_CatLoss ($Billion)	5,018	43.046	32.140	10.500	130.800

Panel B: Differences in sample means between the Cat bond and reinsurance groups

	Cat bond Group (CatBond > 0, N=231)	Reinsurance Group (CatBond = 0, N=4787)	Diff	p>|t|
Reinsurance ratio	0.288	0.275	0.013	0.75
CatBond ($Billion)	0.683	0.000	0.683***	0.000
LogAsset	23.267	19.390	3.877***	0.000
ROA	0.025	0.016	0.009***	0.010
GEO_herf	0.095	0.483	-0.388***	0.000
LOB_herf	0.210	0.517	-0.307***	0.000
Leverage	0.663	0.562	0.101***	0.000
Business/Surplus	1.294	1.520	-0.225**	0.028
LossRatio	0.703	0.709	-0.006	0.748
LossVolatility	0.096	0.164	-0.068***	0.009
Long_tail	0.628	0.689	-0.062***	0.003
CatRisk	0.494	0.447	0.047**	0.047

Table 2: The Role of Cat Bonds on Reinsurance Usage

This table illustrates the effect of Cat bonds on the reinsurance usage in the full sample (columns (1)-(2)), the hard market subsample (columns (3)-(4)) and the soft market subsample (columns (5)-(6)). The dependent variable is *Reinsurance ratio*, defined as the ratio of reinsurance premiums ceded to the sum of the direct premiums written and reinsurance premiums assumed. The main independent variable is *CatBond*, which equals an insurer's total outstanding Cat bonds each year. The Appendix lists the definitions of other variables. Robust standard errors clustered at the firm level are in parentheses. *, **, and *** denote statistical significance at 10%, 5%, and 1%.

	Reinsurance ratio					
	Full Sample		Hard Market		Soft Market	
CatBond	**-0.036*** **	**-0.039*** **	**-0.056*** **	**-0.058*** **	**0.002**	**-0.010**
	(0.010)	**(0.010)**	**(0.019)**	**(0.019)**	**(0.022)**	**(0.020)**
LogAsset		-0.035**		-0.029*		-0.037**
		(0.014)		(0.017)		(0.017)
ROA		0.413***		0.346**		0.450***
		(0.101)		(0.174)		(0.130)
GEO_herf		-0.044		-0.146***		0.028
		(0.035)		(0.052)		(0.050)
LOB_herf		-0.022		-0.018		-0.039
		(0.055)		(0.061)		(0.067)
Leverage		-0.187***		-0.261***		-0.131*
		(0.061)		(0.084)		(0.075)
Business/Surplus		0.045***		0.054***		0.042***
		(0.009)		(0.014)		(0.010)
LossRatio		0.132***		0.100**		0.141***
		(0.034)		(0.047)		(0.047)
LossVolatility		0.007		0.024		-0.008
		(0.017)		(0.026)		(0.023)
Long_tail		-0.072		-0.109		-0.087
		(0.070)		(0.076)		(0.086)
CatRisk		0.092		0.043		0.066
		(0.069)		(0.075)		(0.074)
US_CatLoss		0.001*		0.000		0.000**
		(0.000)		(0.000)		(0.000)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.004	0.113	0.009	0.131	0.003	0.112
Observations	5,018	5,018	1,788	1,788	3,230	3,230

Table 3: Cat Bonds at Risk and Reinsurance Usage

This table illustrates the effect of Cat bonds at risk on the reinsurance usage in the full sample, the hard and the soft market subsamples. The dependent variable is *Reinsurance ratio*. The main independent variable is *CatBond@risk*, which equals the amounts of Cat bonds at risk for an insurer. The Appendix lists the definitions of other variables. Robust standard errors clustered at the firm level are in parentheses. *, **, and *** denote statistical significance at 10%, 5%, and 1%.

	Reinsurance ratio					
	Full Sample		Hard Market		Soft Market	
CatBond@risk	**0.093***	**0.075**	**0.388*****	**0.403*****	**-0.002**	**0.012**
	(0.050)	**(0.058)**	**(0.072)**	**(0.070)**	**(0.040)**	**(0.061)**
LogAsset		-0.035**		-0.030*		-0.037**
		(0.014)		(0.017)		(0.017)
ROA		0.413***		0.359**		0.449***
		(0.101)		(0.175)		(0.130)
GEO_herf		-0.045		-0.149***		0.028
		(0.035)		(0.052)		(0.050)
LOB_herf		-0.019		-0.012		-0.039
		(0.055)		(0.061)		(0.067)
Leverage		-0.186***		-0.260***		-0.130*
		(0.061)		(0.084)		(0.075)
Business/Surplus		0.045***		0.053***		0.042***
		(0.009)		(0.014)		(0.010)
LossRatio		0.132***		0.101**		0.141***
		(0.034)		(0.047)		(0.047)
LossVolatility		0.007		0.022		-0.008
		(0.017)		(0.026)		(0.023)
Long_tail		-0.071		-0.105		-0.087
		(0.071)		(0.076)		(0.086)
CatRisk		0.095		0.048		0.066
		(0.069)		(0.075)		(0.075)
US_CatLoss		0.001*		0.000		0.000**
		(0.000)		(0.000)		(0.000)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.002	0.111	0.002	0.123	0.003	0.112
Observations	5,018	5,018	1,788	1,788	3,230	3,230

Table 4: Propensity Score Matching (PSM)

This table presents analyses of propensity score matching (PSM). We match a Cat bond insurer with a non-Cat bond (reinsurance group) insurer based on firm characteristics, including *LogAsset*, *GEO_herf*, *LOB_herf*, *ROA*, *Business/Surplus, LossRatio*, *LossVolatility*, *Long_tail*, *Leverage*, and *CatRisk*. Panel A presents diagnostic tests to verify that the treated Cat bond (Cat bond insurer) and matched control Group (non-Cat bond insurer) share balanced covariates. It shows the t-tests of the differences of firm characteristics between the two groups. Panel B tests the effect of Cat bonds on reinsurance usage in the matched sample, resembling Table 2. The dependent variable is *Reinsurance ratio* and the main independent variable is *CatBond*. The Appendix lists the definitions of other variables. Robust standard errors clustered at the firm level are in parentheses. *, **, and *** denote statistical significance at 10%, 5%, and 1%.

Panel A: t-tests of the differences of firm characteristics

	Cat bond Group	Matched Control Group	diff	p>|t|
LogAsset	23.267	23.010	0.257	0.123
ROA	0.025	0.025	0.000	0.996
GEO_herf	0.095	0.104	-0.009	0.465
LOB_herf	0.210	0.214	-0.005	0.714
Leverage	0.663	0.652	0.011	0.266
Business/surplus	1.294	1.355	-0.061	0.477
LossRatio	0.703	0.704	0.000	0.97
LossVolatility	0.096	0.074	0.022	0.164
Long_tail	0.628	0.655	-0.028	0.128
CatRisk	0.494	0.491	0.003	0.861

Table 4: Propensity Score Matching (PSM), Continued

Panel B: Multivariate analysis of the matched sample

	Reinsurance ratio (PSM)		
	Full Sample	Hard Market	Soft Market
CatBond	**-0.050*** **	**-0.051** **	**-0.023**
	(0.012)	**(0.020)**	**(0.015)**
LogAsset	0.032	0.026	0.036
	(0.038)	(0.051)	(0.048)
ROA	0.426	0.047	-0.201
	(0.262)	(0.373)	(0.241)
GEO_herf	1.056***	1.162	0.593*
	(0.377)	(0.809)	(0.339)
LOB_herf	0.150	0.336	0.051
	(0.179)	(0.259)	(0.146)
Leverage	-0.594***	-0.247	-0.692***
	(0.212)	(0.223)	(0.216)
Business/surplus	0.099***	0.089**	0.127***
	(0.029)	(0.037)	(0.040)
LossRatio	0.291***	0.139	0.138*
	(0.105)	(0.086)	(0.081)
LossVolatility	0.029	0.060	0.090**
	(0.068)	(0.095)	(0.044)
Long_tail	-0.104	-0.240	-0.114
	(0.190)	(0.285)	(0.151)
CatRisk	0.157	0.048	0.051
	(0.204)	(0.325)	(0.126)
US_CatLoss	-0.001	-0.002**	0.000
	(0.001)	(0.001)	(0.000)
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
R-squared	0.331	0.363	0.369
Observations	462	172	290

Table 5: Heckman Treatment Estimate

This table shows the first and second stages results of Heckman treatment models. The first-stage model is the selection equation, and the second stage tests the effects of *CatBond* on reinsurance usage. The inverse Mills ratio (IMR) estimated from the estimators of the first-stage model is used as a control in the second-stage model to account for potential selection bias. Robust standard errors clustered at the firm level are in parentheses. *, **, and *** denote statistical significance at 10%, 5%, and 1%.

	First Stage	Second Stage (Reinsurance ratio)		
	Probit	Full Sample	Hard Market	Soft Market
CatBond		**-0.049*** **	**-0.066*** **	**-0.010**
		(0.010)	**(0.020)**	**(0.020)**
LogAsset	0.636***	-0.035**	-0.029*	-0.037**
	(0.097)	(0.014)	(0.017)	(0.017)
ROA	-5.168**	0.411***	0.343**	0.449***
	(2.108)	(0.101)	(0.174)	(0.130)
GEO_herf	-0.366	-0.043	-0.145***	0.028
	(0.464)	(0.035)	(0.052)	(0.050)
LOB_herf	-1.149**	-0.022	-0.017	-0.039
	(0.581)	(0.055)	(0.061)	(0.067)
Leverage	1.691	-0.187***	-0.259***	-0.131*
	(1.313)	(0.061)	(0.083)	(0.075)
Business/surplus	0.026	0.045***	0.054***	0.042***
	(0.131)	(0.009)	(0.014)	(0.010)
LossRatio	-1.848**	0.132***	0.100**	0.141***
	(0.725)	(0.034)	(0.047)	(0.047)
LossVolatility	0.248	0.007	0.025	-0.008
	(0.223)	(0.017)	(0.026)	(0.023)
Long_tail	-0.533	-0.073	-0.110	-0.087
	(0.594)	(0.071)	(0.076)	(0.086)
CatRisk	1.168**	0.094	0.045	0.066
	(0.561)	(0.069)	(0.075)	(0.075)
US_CatLoss	-0.004	0.001*	0.000	0.000**
	(0.003)	(0.000)	(0.000)	(0.000)
IMR		0.012	0.011	0.000
		(0.010)	(0.022)	(0.006)
BBbond	-7.377**			
	(3.369)			
Year FE	Yes	Yes	Yes	Yes
Firm FE	No	Yes	Yes	Yes
R-squared	0.512	0.114	0.131	0.112
Observations	5,018	5,018	1,788	3,230

Table 6: Lagging in the Cat Bond Variable

This table lags outstanding Cat bonds in the baseline model to test the relationship between reinsurance usage and Cat bonds. The dependent variable is *Reinsurance ratio* and the main independent variable is *LagCatBond*. The Appendix lists the definitions of other variables. Robust standard errors clustered at the firm level are in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels.

	Reinsurance ratio		
	Full Sample	Hard Market	Soft Market
LagCatBond	**-0.056*** **	**-0.074*** **	**-0.014**
	(0.014)	**(0.023)**	**(0.016)**
LogAsset	-0.039**	-0.031	-0.039**
	(0.016)	(0.030)	(0.019)
ROA	0.367***	0.127	0.461***
	(0.122)	(0.242)	(0.135)
GEO_herf	-0.014	-0.104	0.065
	(0.046)	(0.072)	(0.068)
LOB_herf	-0.080	-0.112	-0.064
	(0.060)	(0.091)	(0.069)
Leverage	-0.257***	-0.348***	-0.183**
	(0.074)	(0.122)	(0.089)
Business/surplus	0.046***	0.041***	0.044***
	(0.009)	(0.015)	(0.012)
LossRatio	0.121***	0.035	0.153***
	(0.040)	(0.075)	(0.047)
LossVolatility	0.027*	0.074*	0.020
	(0.015)	(0.042)	(0.014)
Long_tail	-0.089	-0.152*	-0.099
	(0.073)	(0.089)	(0.092)
CatRisk	0.109	0.108	0.071
	(0.071)	(0.088)	(0.085)
US_CatLoss	0.001*	-0.000	0.000**
	(0.001)	(0.001)	(0.000)
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
R-squared	0.117	0.121	0.120
Observations	4,206	1,251	2,955

Table 7: Two-stage Least Squares (2SLS)

This table presents analyses of 2SLS regression with instrument variable. The instrument (*IV*) is the outstanding Cat bonds, adjusted for the new issue amount of Cat bonds and the amount of Cat bonds that become at risk, for an insurer i in year t. In the second stage regressions, the dependent variable is *Reinsurance ratio*. The main independent variable is $\widehat{CATbond}$, which is the fitted value of outstanding Cat bonds derived from the first stage model. The Appendix lists the definitions of other variables. Robust standard errors clustered at the firm level are in parentheses. *, **, and *** denote statistical significance at 10%, 5%, and 1%.

	Reinsurance ratio					
	Full Sample		Hard Market		Soft Market	
	1st stage	2nd stage	1st stage	2nd stage	1st stage	2nd stage
$\widehat{CATbond}$		**-0.052*** **		**-0.063*** **		**-0.019**
		(0.010)		**(0.018)**		**(0.020)**
IV	1.091***		1.211***		1.004***	
	(0.048)		(0.031)		(0.092)	
LogAsset	0.001	-0.035**	0.002	-0.029*	0.001	-0.037**
	(0.003)	(0.014)	(0.003)	(0.017)	(0.004)	(0.017)
ROA	-0.004	0.413***	-0.009	0.345**	0.010	0.450***
	(0.008)	(0.100)	(0.023)	(0.174)	(0.014)	(0.129)
GEO_herf	0.008	-0.043	0.008	-0.145***	0.007	0.028
	(0.005)	(0.035)	(0.008)	(0.052)	(0.006)	(0.050)
LOB_herf	-0.017**	-0.023	-0.007	-0.018	-0.022*	-0.040
	(0.007)	(0.055)	(0.005)	(0.061)	(0.012)	(0.067)
Leverage	-0.006	-0.187***	-0.008	-0.261***	-0.014	-0.131*
	(0.010)	(0.061)	(0.012)	(0.083)	(0.015)	(0.075)
Business/surplus	0.000	0.045***	-0.001	0.054***	0.001	0.042***
	(0.001)	(0.009)	(0.001)	(0.014)	(0.001)	(0.010)
LossRatio	0.004	0.132***	0.000	0.100**	0.008	0.141***
	(0.003)	(0.034)	(0.003)	(0.047)	(0.005)	(0.047)
LossVolatility	0.003	0.007	-0.001	0.024	0.007	-0.008
	(0.002)	(0.017)	(0.002)	(0.026)	(0.005)	(0.022)
Long_tail	-0.013	-0.073	-0.017	-0.109	-0.014	-0.087
	(0.009)	(0.070)	(0.012)	(0.076)	(0.015)	(0.086)
CatRisk	-0.024	0.091	-0.009	0.043	-0.029	0.066
	(0.017)	(0.069)	(0.013)	(0.074)	(0.023)	(0.074)
US_CatLoss	0.000	-0.000	0.000	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared		0.113		0.131		0.112
Observations	4,901	4,901	1,645	1,645	3,119	3,119

Table 8: The Impact of Cat Bonds on Internal and External Reinsurance Usage

This table explores the role of Cat bonds on internal and external reinsurance usage. The dependent variables are internal (*In-Rein*) and external reinsurance (*Ex-Rein*). Internal (external) reinsurance ratio equals reinsurance premiums ceded to affiliates (nonaffiliates) divided by the sum of direct premiums written and total reinsurance premiums assumed. The main independent variable is *CatBond*. The Appendix lists the definitions of other variables. Robust standard errors clustered at the firm level are in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels.

	Full Sample		Hard Market		Soft Market	
	Ex-Rein	In-Rein	Ex-Rein	In-Rein	Ex-Rein	In-Rein
CatBond	**0.017***	**-0.054*****	**0.024***	**-0.081*****	**-0.001**	**-0.007**
	(0.010)	**(0.015)**	**(0.013)**	**(0.023)**	**(0.010)**	**(0.017)**
LogAsset	-0.021	-0.013	-0.027*	-0.001	-0.017	-0.020
	(0.013)	(0.012)	(0.014)	(0.014)	(0.017)	(0.016)
ROA	0.306***	0.107*	0.194	0.147*	0.415***	0.040
	(0.101)	(0.061)	(0.159)	(0.079)	(0.125)	(0.069)
GEO_herf	-0.028	-0.011	-0.027	-0.118**	-0.036	0.071
	(0.042)	(0.038)	(0.048)	(0.054)	(0.059)	(0.053)
LOB_herf	0.012	-0.038	0.008	-0.028	0.025	-0.066
	(0.059)	(0.052)	(0.070)	(0.066)	(0.065)	(0.051)
Leverage	-0.078	-0.101**	-0.089	-0.174***	-0.138**	0.017
	(0.054)	(0.048)	(0.069)	(0.065)	(0.069)	(0.052)
Business/surplus	0.036***	0.009**	0.037***	0.017*	0.043***	-0.001
	(0.008)	(0.004)	(0.013)	(0.009)	(0.010)	(0.005)
LossRatio	0.070**	0.060***	0.021	0.079***	0.116**	0.023*
	(0.033)	(0.016)	(0.042)	(0.026)	(0.047)	(0.013)
LossVolatility	0.018	-0.009	-0.001	0.026*	0.003	-0.009
	(0.013)	(0.012)	(0.024)	(0.015)	(0.013)	(0.015)
Long_tail	-0.103	0.029	-0.140*	0.032	-0.118*	0.030
	(0.063)	(0.043)	(0.076)	(0.054)	(0.070)	(0.053)
CatRisk	0.036	0.051	0.044	-0.008	0.017	0.047
	(0.050)	(0.062)	(0.061)	(0.067)	(0.053)	(0.061)
US_CatLoss	0.001	0.000	0.000	-0.000	0.000	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.084	0.039	0.074	0.098	0.113	0.018
Observations	5,018	5,018	1,788	1,788	3,230	3,230

Table 9: Insolvency Risk, Cat Bonds and External Reinsurance Usage

This table tests the effect of insolvency risk. The dependent variable is external reinsurance *(Ex-Rein)*. The main independent variable is *CatBond*. The Appendix lists the definitions of other variables. A dummy variable, "*HighLeverage,*" takes a value of one if an insurer has high leverage (top 25%) as a measure of insolvency risk. Robust standard errors clustered at the firm level are in parentheses. *, **, and *** denote statistical significance at 10%, 5%, and 1%.

	Ex-Rein					
	Full Sample		Hard Market		Soft Market	
CatBond	**0.027**	**-0.050**	**-0.024***	**-0.182****	**0.003**	**0.022**
	(0.040)	**(0.098)**	**(0.014)**	**(0.092)**	**(0.011)**	**(0.098)**
CatBond *HighLeverage	**-0.011**		**0.050*****		**-0.004**	
	(0.041)		**(0.018)**		**(0.014)**	
CatBond *Leverage		**0.097**		**0.297****		**-0.034**
		(0.142)		**(0.128)**		**(0.150)**
LogAsset	-0.021	-0.021	-0.027*	-0.028*	-0.017	-0.017
	(0.013)	(0.013)	(0.014)	(0.014)	(0.017)	(0.017)
ROA	0.306***	0.306***	0.194	0.194	0.415***	0.415***
	(0.101)	(0.101)	(0.159)	(0.159)	(0.125)	(0.125)
GEO_herf	-0.028	-0.028	-0.027	-0.028	-0.036	-0.036
	(0.042)	(0.042)	(0.048)	(0.048)	(0.059)	(0.059)
LOB_herf	0.012	0.012	0.008	0.009	0.025	0.025
	(0.059)	(0.059)	(0.070)	(0.070)	(0.066)	(0.065)
Leverage	-0.078	-0.078	-0.089	-0.092	-0.138**	-0.138**
	(0.054)	(0.054)	(0.069)	(0.069)	(0.069)	(0.069)
Business/surplus	0.036***	0.036***	0.037***	0.037***	0.043***	0.043***
	(0.008)	(0.008)	(0.013)	(0.013)	(0.010)	(0.010)
LossRatio	0.070**	0.070**	0.021	0.021	0.116**	0.116**
	(0.033)	(0.033)	(0.042)	(0.042)	(0.047)	(0.047)
LossVolatility	0.018	0.018	-0.001	-0.001	0.003	0.003
	(0.013)	(0.013)	(0.024)	(0.024)	(0.013)	(0.013)
Long_tail	-0.103	-0.103	-0.140*	-0.140*	-0.118*	-0.118*
	(0.063)	(0.063)	(0.076)	(0.075)	(0.070)	(0.070)
CatRisk	0.036	0.036	0.045	0.044	0.017	0.017
	(0.050)	(0.050)	(0.061)	(0.061)	(0.053)	(0.053)
US_CatLoss	0.001	0.001	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.084	0.084	0.075	0.076	0.113	0.113
Observations	5,018	5,018	1,788	1,788	3,230	3,230

Table 10: The Impact of Cat Bonds on Cat and non-Cat Reinsurance Usage

This table tests the role of Cat bonds on Cat reinsurance usage (*Cat Rein*) in Panel A and non-Cat reinsurance usage (*non-Cat Rein*) in Panel B. *Cat Rein* equals the ratio of reinsurance premiums ceded in generalized Cat lines divided by the sum of direct premiums written in generalized Cat lines and total reinsurance premiums assumed in generalized Cat lines. Similarly, *non-Cat Rein* is estimated based on non-Cat lines. The main independent variable is *CatBond*. The Appendix lists the definitions of other variables. Robust standard errors clustered at the firm level are in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels.

Panel A: The role of Cat bonds on Cat reinsurance usage

	Cat_Rein		
	Full Sample	Hard Market	Soft Market
CatBond	**-0.045*** **	**-0.062*** **	**-0.011**
	(0.012)	**(0.021)**	**(0.025)**
LogAsset	-0.022	-0.026	-0.020
	(0.014)	(0.017)	(0.017)
ROA	0.298***	0.381***	0.239**
	(0.085)	(0.116)	(0.105)
GEO_herf	0.044	-0.052	0.076
	(0.043)	(0.060)	(0.063)
LOB_herf	-0.015	0.010	0.014
	(0.065)	(0.082)	(0.087)
Leverage	-0.151***	-0.263***	-0.089
	(0.058)	(0.079)	(0.076)
Business/surplus	0.039***	0.047***	0.035***
	(0.008)	(0.015)	(0.009)
LossRatio	0.077***	0.088***	0.055**
	(0.017)	(0.022)	(0.023)
LossVolatility	-0.013	-0.017	-0.001
	(0.010)	(0.017)	(0.017)
Long_tail	-0.116	-0.143	-0.163
	(0.076)	(0.090)	(0.103)
CatRisk	0.118*	0.039	0.118
	(0.072)	(0.091)	(0.078)
US_CatLoss	0.000	0.000	0.000*
	(0.000)	(0.000)	(0.000)
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
R-squared	0.064	0.087	0.057
Observations	5,018	1,788	3,230

Table 10: The Impact of Cat Bonds on Cat and non-Cat Reinsurance Usage, Continued

Panel B: The role of Cat bonds on non-Cat reinsurance usage

	non-Cat Rein		
	Full Sample	Hard Market	Soft Market
CatBond	**-0.025*** **	**-0.040*** **	**0.003**
	(0.007)	**(0.016)**	**(0.015)**
LogAsset	-0.013	-0.005	-0.013
	(0.011)	(0.013)	(0.013)
ROA	0.160*	0.020	0.208*
	(0.082)	(0.128)	(0.116)
GEO_herf	-0.059*	-0.090**	-0.006
	(0.031)	(0.042)	(0.034)
LOB_herf	-0.003	-0.015	-0.002
	(0.036)	(0.041)	(0.038)
Leverage	-0.101**	-0.130**	-0.057
	(0.044)	(0.063)	(0.050)
Business/surplus	0.021***	0.023***	0.022***
	(0.006)	(0.008)	(0.007)
LossRatio	0.071**	0.023	0.091*
	(0.034)	(0.041)	(0.050)
LossVolatility	0.014	0.044	-0.006
	(0.017)	(0.028)	(0.015)
Long_tail	0.091**	0.043	0.110***
	(0.035)	(0.041)	(0.036)
CatRisk	-0.218***	-0.234***	-0.259***
	(0.064)	(0.070)	(0.060)
US_CatLoss	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
R-squared	0.100	0.113	0.128
Observations	5,018	1,788	3,230

Appendix: Variable Definitions

Variable	Definition
Reinsurance ratio	The ratio of reinsurance premiums ceded to the sum of the direct premiums written and reinsurance premiums assumed.
In-Rein	Reinsurance premiums ceded to affiliates divided by the sum of direct premiums written and total reinsurance premiums assumed
Ex-Rein	Reinsurance premiums ceded to nonaffiliates divided by the sum of direct premiums written and total reinsurance premiums assumed
Cat Rein	The ratio of reinsurance premiums ceded in generalized Cat lines divided by the sum of direct premiums written in generalized Cat lines and total reinsurance premiums assumed in generalized Cat lines
non-Cat Rein	The ratio of reinsurance premiums ceded in generalized non-Cat lines divided by the sum of direct premiums written in generalized non-Cat lines and reinsurance premiums assumed in generalized non-Cat lines
CatBond	The total amount of outstanding catastrophe bonds for insurer i in year t
CatBond@risk	The amount of Cat bonds at risk, get close to trigger or default, for insurer i in year t
IV	The total amount of outstanding catastrophe bonds, adjusted for the new issue amount of catastrophe bonds and the amount of catastrophe bonds that become at risk, for an insurer in a given year.
LogAsset	The log of a ceding insurer's admitted assets
ROA	Return on assets
LOB_herf	Herfindahl index of lines of business
GEO_herf	Herfindahl index of geographical regions
Leverage	The ratio of liabilities to total assets
Business/surplus	The ratio of direct business written to surplus
LossRatio	The ratio of incurred losses to earned premiums
LossVolatility	Standard deviation of loss ratios over the last five years
Long_tail	The proportion of direct premiums written in workers' compensation and other long-tail lines to total premiums. Long-tail lines include farm multiperil, homeowners' multiperil, commercial multiperil, medical malpractice, workers' compensation, product liability, automobile liability, and "other" liability.
CatRisk	The ratio of direct premiums written in Cat lines to total premiums written. Cat lines include homeowners, fire, allied, commercial multiperil, earthquake, farm owners, auto physical damage, and inland marine.
US_CatLoss	U.S. insured losses of Cat events in a year