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Measuring the liquidity impact on catastrophe bond spreads

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ABSTRACT

This study measures liquidity in the catastrophe (CAT) bond market and the liquidity premium embedded in CAT bond spreads. The empirical results show that *time to maturity, yield volatility,* and *yield dispersion from the primary market* are the three most effective liquidity proxies. Given these three proxies, the average estimated liquidity premium in the CAT bond market is 67.57bps, accounting for only 9.42% of the average CAT bond spread (717.37bps) in the secondary market during the period 2002-2016. The average CAT bond liquidity premium is higher than the corporate bond liquidity premium of a similar risk class by about 35bps during the pre-crisis period. The more significant part of the high-yield spreads, 90.58%, is attributed to other risk natures of CAT bonds. Lastly, the liquidity premium increases dramatically after occurrences of severe natural catastrophes as well as during the 2008 financial crisis.

1. Introduction

Catastrophe (CAT) bonds, which are a type of insurance-linked securities (ILS), can resolve inefficiency in the reinsurance market and have been by far one of the most successful securitization structures to date (Cummins and Trainar, 2009).[1] CAT bonds are a high-yield financial instrument, presenting an average spread of 717.37 basis points (bps) over LIBOR (London Interbank Offered Rate) and an excess spread of 322.74bps compared to similarly rated corporate bonds during the period 2002: Q2 to 2016: Q1. One theory is that their high-yield spreads are due to their liquidity premium, because CAT bonds are not publicly traded and their transactions are in the over-the-counter market (OTC). Various studies indicate that liquidity is factored into corporate bond yield spreads (Houweling et al., 2005; Chen et al., 2007; Bao et al., 2011; Dick-Nielsen et al., 2012; Schestag et al., 2016; Lo et al., 2019; etc.), but there is no evidence on how liquidity is related to CAT bond spreads.

While we do not find any literature investigating the liquidity effect on CAT bond spreads, some relevant studies (Braun, 2016; Gürtler et al., 2016) do consider *issue volume*, *maturity*, and *time to maturity* in order to measure CAT bond liquidity in the primary market or secondary market for such bonds.[2] To our surprise, these studies find no empirical evidence to support the liquidity hypothesis, implying that investors do not demand a liquidity premium for CAT bonds. Based on the above background, this study looks to examine whether the liquidity premium is present and, if so, to measure how much it is embedded in CAT bond spreads.

Previous studies of CAT bonds focus on finding price determinants of their yield spreads. The known bond-specific factors that help determine these spreads include expected losses (Papachristou, 2011; Galeotti et al., 2013, Chang et al., 2018; etc.), trigger

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[1] CAT bonds can help resolve inefficiency in the reinsurance market, because correlated CAT risks within insurance markets may be uncorrelated with other risks in the economy (Chen et al., 2008; Cummins and Trainar, 2009).

[2] See Cummins et al. (2004), Papachristou (2011), Chen et al. (2018), Dieckmann (2019), etc.

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mechanisms, bond ratings, etc. (Lee and Yu, 2002; Cummins et al., 2004; Dieckmann, 2019). Some studies suggest that macroeconomic factors, conditions of reinsurance markets, and catastrophe events influence CAT bond spreads (Braun, 2016; Gürtler et al., 2016).[3]

This study analyzes the liquidity effect on CAT bond spreads during the period 2002: Q2 to 2016: Q1[4] and evaluates the performance of eight bond liquidity proxies proposed in the literature. Because CAT bond transactions are in the OTC market, it is difficult to obtain transaction data to form a direct liquidity measure, such as the bid-ask spread. We follow the literature on corporate bond liquidity in the OTC market and use bond characteristics and related market information to evaluate eight indirect proxies of CAT bond liquidity: *issued amount (Amount)*, *sponsor (Sponsor)*, *number of perils (Nperils)*, *maturity (MT)*, *time to maturity (TTM)*, *yield volatility (Volatility)*, *yield spread dispersion from the primary market (Dispersion)*, and *yield spread dispersion from the expert forecast (DispersionE)*.

We employ two approaches to examine the liquidity effect on CAT bond spreads. In the first approach of liquidity-sorted portfolios, we order all bonds in the sample by their value of liquidity proxy j and create five mutually exclusive portfolios for each proxy j. The sort order is chosen such that portfolio 1 contains the bonds that are considered to be the most liquid, and portfolio 5 contains the most illiquid. We look into the average spreads and average liquidity proxies from portfolio 1 (liquid bonds) to portfolio 5 (illiquid bonds). We then conduct a regression analysis of each liquidity-sorted portfolio to observe patterns of the constant term and the R-squared from the most liquid portfolio to the most illiquid portfolio for liquidity proxy j after controlling other sources of risk, such as expected losses, trigger mechanisms, macroeconomic factors, etc. In the second approach of the entire sample analysis, we add the eight possible proxies of CAT bond liquidity respectively and run the entire sample regression analysis to examine which liquidity proxy has a significant effect on CAT bond spreads.

Our results from the above two approaches show that four out of eight proxies - *time to maturity* (TTM), *yield volatility* (Volatility), *yield spread dispersion from the primary market* (Dispersion), and *yield spread dispersion from the expert forecast* (DispersionE) - capture the liquidity effect on CAT bond spreads. Next, we run comparison tests for our four liquidity proxies to identify if some proxies work better than others. As a CAT bond liquidity measure, the yield spread dispersion from the expert forecast (DispersionE) reflects the heterogeneous beliefs on CAT risk between CAT bond investors and expert forecasts using natural catastrophe risk models. However, the yield spread dispersion from the expert forecast (DispersionE) does not add explanatory power to yield spread dispersion from the primary market (Dispersion), and hence Dispersion works better as a CAT bond liquidity proxy than DispersionE. Three liquidity proxies (time to maturity, yield volatility, and yield spread dispersion from the primary market (Dispersion)) have significant effects on CAT bond spreads in all comparison tests and are still effective in a series of robustness tests with different regression models and subsamples. Thus, this study provides evidence that these three liquidity proxies are the most effective for CAT bond liquidity.

Given these three effective liquidity proxies, we show that the average liquidity risk premium for CAT bonds is about 67.57bps during our sample period 2002: Q2 to 2016: Q1. Both Hurricane Katrina (in August 2005) and the 2008 financial crisis (triggered by the bankruptcy of Lehman Brothers in September 2008) did significantly affect the liquidity risk in the CAT bond market, as we see that the average liquidity premium increases from 35.55bps in 2005: Q3 to 142.47 in 2006: Q3 after Hurricane Katrina and peaks at 219.46bps around the 2008 financial crisis. Note that the liquidity premium after the 2008 financial crisis exhibits a declining trend along with a sustainable growth of the CAT bond market.

This study makes the following contributions to the extant literature and offers practical value for investment management. First, we compile the most comprehensive dataset from a multitude of both primary and secondary market data sources for CAT bonds over the period 2002: Q2 to 2016: Q1. The dataset consists of 464 CAT bonds with 4,751 observations of bond spreads.

Second, as neither practitioner (Papachristou, 2011) nor academics (Braun, 2016; Gürtler et al., 2016; Dieckmann, 2019) endorse any consensus on common proxies of measuring CAT bond liquidity, our study presents four effective liquidity proxies for CAT bonds: time to maturity, yield volatility, yield spread dispersion from the primary market, and yield spread dispersion from the expert forecast. Further comparison tests show that time to maturity, yield volatility, and yield spread dispersion from the primary market are the three most effective proxies and reflect different dimensions' liquidity effects on CAT bond spreads.

Third, previous studies (Braun, 2016; Gürtler et al., 2016; Dieckmann, 2019) do not find empirical evidence for the liquidity premium of CAT bonds. Our findings show that liquidity is indeed priced into CAT bond spreads, thus filling the research gap in the literature. The mean value of the liquidity premium is 67.57bps, contributing 9.42% to the total 717.37bps of the spread in the CAT bond secondary market. The liquidity premium explains only a small portion of the high-yield spreads of CAT bonds, as a large proportion of the spreads is found to be positively associated with CAT risk.[5]

The remainder of this paper is structured as follows. The next section defines eight possible liquidity proxies for CAT bonds and develops liquidity hypotheses. Section 3 describes the data and variables. Section 4 presents and discusses our empirical analysis. Finally, the last section summarizes our main results and concludes.

[3] For example, CAT bonds represent an alternative to traditional reinsurance, and there should be a positive correlation between traditional reinsurance premiums and CAT bond spreads.

[4] Secondary data are provided since June 2002.

[5] This evidence that the CAT bond market can efficiently price CAT risk and bond spreads containing significantly predictive ability for future CAT losses is consistent with the view of prediction markets (Wolfers and Zitzewitz, 2004; Arrow et al., 2008; Ennis, 2008; Zhao and Yu, 2018).

2. CAT bonds and Asia Pacific markets

The CAT bond market has expanded rapidly over the recent decade. According to Artemis.bm, the values of 2018 CAT bond & ILS issuances and outstanding bonds are $13.85 billion and $37.83 billion, respectively.[6] Fig. 1 shows CAT bonds & ILS issuuances and those outstanding by year from 1997 to 2018.

The Asia Pacific region, as one of the world's most disaster-prone areas, is the most likely source of global expansion for CAT bond and other ILS markets in recent years. The Guy Carpenter 2018 Asia Pacific Catastrophe Reinsurance report shows that CAT bonds and other ILS have reached an estimated $82 billion in the Asia Pacific, or approximately 20% of the global catastrophe risk limit. The amount of CAT bond outstanding that covers risk in the Asia Pacific region has risen 260% since 2004 to $3.5 billion in September 2018. At the end of 2018, 91 CAT bonds had been issued to cover risks in the Asia Pacific region at a total amount of over $15 billion. Japanese typhoons and earthquakes are the most common perils covered by CAT bonds in the Asia Pacific region, attributing to 75 CAT bonds with a cumulative amount of over $12.5 billion. Australia and New Zealand are the second largest region, taking up 14 CAT bonds with about $2.6 billion in aggregate amount. Taiwan even issued one CAT bond for $100 million in 2003, while China issued one for $50 million in 2015. Indonesia and other Southeast Asia emerging markets are also set to open up to CAT bonds.[7]

Investors of CAT bonds pay a principal to buy the bonds and receive the coupon according to the contract. The key difference between CAT bonds and common corporate bonds is that CAT bonds have trigger mechanisms, and investors may lose part or all of the principal/coupons when CAT risk hits the trigger level. The core idea behind the catastrophe securitization structure of a CAT bond is that a sponsor, usually an insurer/reinsurer, enters into an alternative reinsurance contract with a Special Purpose Vehicle (SPV), and thus the sponsor is protected against high losses from a well-defined catastrophe up to a certain limit. To guarantee insurance coverage up to that limit, the SPV issues CAT bonds to investors.

Investors buy CAT bonds, because they generally have higher spreads than comparably rated corporate bonds, as long as they are not triggered (e.g., Cummins, 2012). Investors also buy these securities, because catastrophe risk is largely uncorrelated with the return on other investments in a traditional capital market, and thus these bonds can be regarded as "zero-beta" securities to help them achieve a certain degree of diversification (Hood et al., 2013). The main investors of CAT bonds are hedge funds, specialized catastrophe-oriented funds, mutual funds, life insurers, reinsurers, and banks. Specialized catastrophe-oriented funds that play a significant role in the sector include Nephila Capital, Credit Suisse ILS Strategies, and LGT ILS Partners, among many others. Several mutual funds and hedge fund managers also invest in CAT bonds, such as Oppenheimer Funds, TIAA-Cref, Pine River Capital, and PIMCO.[8]

3. Liquidity hypotheses

We now consider the eight different proxies (issued amount (Amount), sponsor (Sponsor), number of perils (Nperils), maturity (MT), time to maturity (TTM), yield volatility (Volatility), yield spread dispersion from the primary market (Dispersion), and yield spread dispersion from the expert forecast (DispersionE)) to measure CAT bond liquidity and to develop relevant hypotheses for each liquidity proxy.

The issued amount can be regarded as an indirect liquidity measure, because bonds of large issuances should trade more often, as Fisher (1959) first proposes. Sarig and Warga (1989) and Amihud and Mendelson (1991) find that bonds of smaller issued amounts have lower liquidity, because they tend to be locked into buy-and-hold portfolios more easily. Edwards et al. (2007) present that bonds with large issued amounts have lower information costs. For the CAT bond market, Dieckmann (2019) does not find supporting evidence, while Braun (2016) offers weak evidence for the suspected liquidity advantage of larger bond issues on pricing using the primary market CAT bond data. However, Gürtler et al. (2016) note that a larger issued amount leads to higher bond spreads in the secondary CAT bond market, which is in contrast to the liquidity hypothesis. To summarize the above, we formulate the following hypothesis (H1) for a CAT bond's issued amount in the secondary market.

H1. (Amount): Investors demand higher CAT bond spreads for a lower issued amount.

Well-respected sponsors of CAT bonds always disclose more information on the financial situation of the issuers and offer investors a better perception of credit risk. Alexander et al. (2000) and Li et al. (2019) argue that greater disclosure of information means a lower transaction cost, and so CAT bonds with well-respected sponsors are more liquid. In the primary market, well-respected sponsors with a strong track record can afford to pay lower CAT bond spreads. Thus, in accordance with the literature, we assume the following hypothesis (H2) in the secondary market.

H2. (Sponsor): Investors demand lower spreads on CAT bonds from well-respected sponsors.

A CAT bond can insure a single peril or multiple perils, which include peril type and peril region. Sponsors prefer to issue multiple peril bonds as they help reduce issuance costs and spread limits over several risk regions (Guy Carpenter, 2006). However, multiple peril types or peril regions within a single CAT bond mean a more complex CAT bond contract, which may make the trading of

[6] Artemis.bm: http://www.artemis.bm/

[7] Singapore has fired the latest shots in the global battle for the catastrophe bond market, promising to pay the upfront costs of new issues starting from 2018.

[8] The trading information comes from http://www.artemis.bm/ils_fund_managers

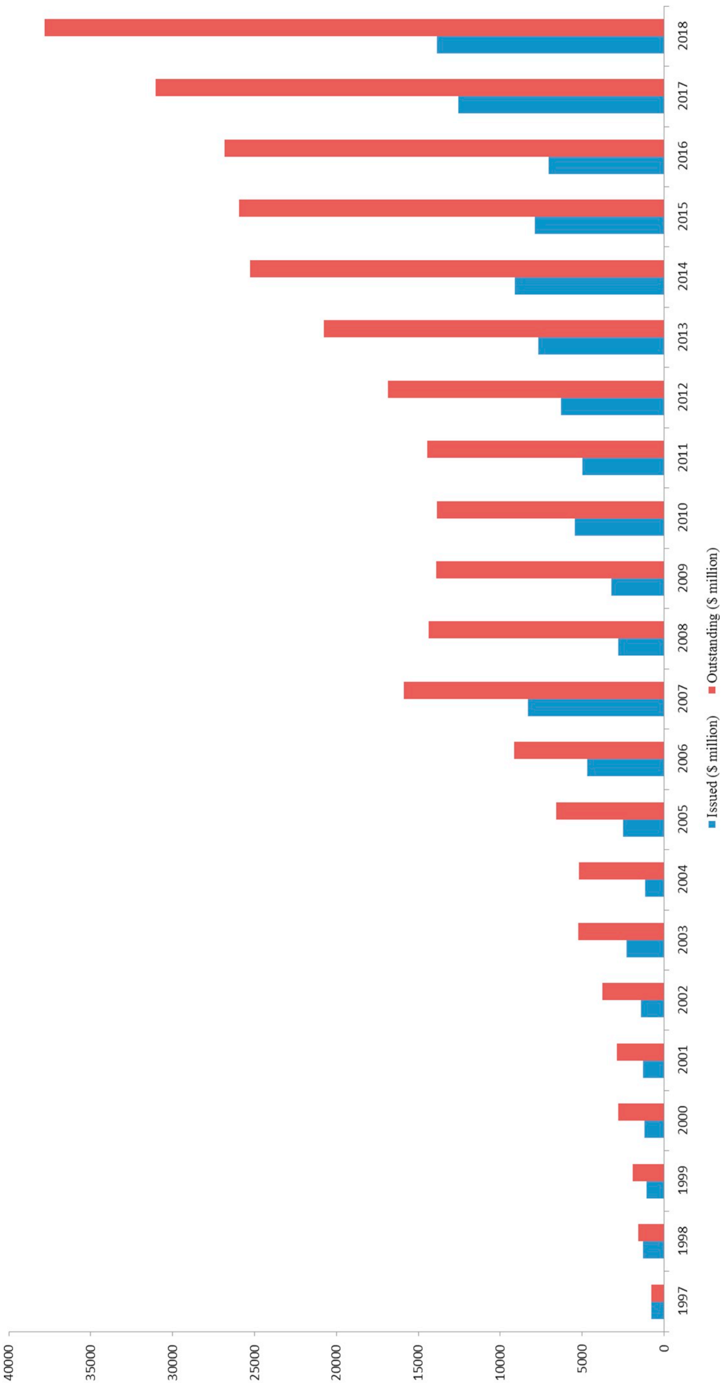

Fig. 1. Catastrophe (CAT) bonds & insurance-linked securities (ILS) issued and outstanding by year.
Source: Artemis.bm

multiple peril bonds less liquid (Gürtler et al., 2016). Based on these thoughts, we postulate the following hypothesis.

H3. (Nperils): CAT bond spreads increase with the number of perils within a single CAT bond.

According to Edwards et al. (2007), corporate bonds close to maturity have lower transaction costs, thus leading to greater liquidity and a lower bond premium. However, for the CAT bond market, Dieckmann (2019) analyzes only 61 CAT bonds, finds that time to maturity (TTM) does not increase the level of CAT bond spreads, and shows that the bond maturity period (MT) does not have a significant influence on CAT bond spreads. Braun (2016) also uses bond maturity as a liquidity measure in the primary market and presents that the bond maturity period does not have a significant influence on CAT bond spreads. Gürtler et al. (2016) employ the bond maturity period (MT) and time to maturity (TTM) to measure CAT bond liquidity in the secondary markets for CAT bonds, concluding that investors do not demand a liquidity premium for CAT bonds and that the liquidity hypothesis is rejected in the secondary CAT bond market from 2002 to 2012. Based on these considerations, we propose the following two hypotheses.

H4. (MT): CAT bond spreads increase with longer maturity periods.

H5. (TTM): CAT bonds with a shorter time to maturity have a lower bond spread.

Yield volatility has always been considered as information uncertainty. Houweling et al. (2005) argue that higher volatility leads to larger bid-ask spreads and thus lower liquidity and higher liquidity premiums. Shulman et al. (1993) find that yield volatility has a significantly positive effect on bond spreads. Hong and Warga (2000) provide evidence for a positive correlation between yield volatility and bid-ask bond spreads. We thus consider the following hypothesis.

H6. (Volatility): A higher yield volatility of a CAT bond denotes a higher bond spread.

Tychon and Vannetelbosch (2002) argue that the more heterogeneous beliefs there are, the larger the liquidity premium is for a bond. Yield dispersion can measure bond liquidity, because the dispersion of a bond yield reflects the extent to which market participants agree on the value of the bond (Houweling et al., 2005). We define the yield dispersion of CAT bond i at quote date t as the standard deviation of secondary market CAT bond spreads relative to the CAT bond spreads in the primary market (at issuance). More heterogeneous beliefs of market participants lead to greater yield dispersion, implying a larger liquidity risk premium. We use yield spread dispersion from the primary market (Dispersion) to proxy for CAT bond liquidity.

$$Dispersion_i = \sqrt{\sum_t \left(\frac{y_{it} - \bar{y}_i}{\bar{y}_i}\right)^2},$$

where y_{it} is the secondary market spread of CAT bond i at quote date t, and $\bar{y}_i$ is the spread of CAT bond i at issuance (in the primary market).

Another yield dispersion variable generated by expected loss is represented by the heterogeneous beliefs between market investors and expert forecasts.

$$DispersionE_i = \sqrt{\sum_t \left(\frac{y_{it} - EL_i}{EL_i}\right)^2},$$

where y_{it} is the secondary market spread of CAT bond i at quote date t, and (EL_i) is the expected loss for each CAT bond i estimated by different natural catastrophe risk models of specialized firms at the time of issuance, which can be regarded as expert forecasts for CAT risk. We thus develop the following two hypotheses.

H7. (Dispersion): Investors demand higher liquidity premiums for CAT bonds with a larger yield dispersion from the primary market.

Table 1
Overview of 8 liquidity proxies.

Liquidity proxy	Details	Expected sign[a]
Issued amount (Amount)	$ million	−
Sponsor	1 if a CAT bond is issued by Swiss Re and 0 otherwise	−
Number of perils (Nperils)	The value ranges from 1 to 8 1 if CAT bond contracts only include windstorms or earthquakes in the one region and 8 if CAT bond contracts involve both windstorms and earthquakes in the U.S., Europe, Japan, and other areas	+
Maturity (MT)	Maturity period in months	+
Time to maturity (TTM)	Time between maturity date and quote date in months	+
Yield volatility (Volatility)	Standard deviation of CAT bond spreads	+
Yield dispersion from the primary market (Dispersion)	Standard deviation of bond spreads between the secondary and the primary market yields	+
Yield dispersion from the expert forecast (DispersionE)	Standard deviation between CAT bond spreads and expected loss estimated by expert forecasts	+

[a] Expected sign of the relationship between the liquidity proxies and CAT bond spreads.

H8. (DispersionE): Investors demand higher liquidity premiums for CAT bonds with a larger yield dispersion from the expert forecast.

Table 1 displays the definitions of liquidity proxies and the expected signs of the relationship between the proxies and CAT bond spreads.

4. Data

Data on CAT bonds are taken from Lane Financial LLC and the Artemis Deal Directory over 2002: Q2 to 2016: Q1.[9] In order to ensure data accuracy, we cross-checked the data against the annual reports of Guy Carpenter and removed samples with missing fields. There are 464 CAT bond tranches and 4,751 market observations, including data on spread, expected loss, amount, maturity, rating, and sponsor. We also collect other features of CAT bonds, such as covered territory, peril, and trigger type from Artemis. This dataset represents virtually the whole universe of CAT bonds that have been issued during our sample period.

4.1. Variables

In addition to the eight liquidity proxies in Table 1, we define the following five CAT bond-specific variables and three macroeconomic variables that may influence CAT bond spreads, as suggested in the literature.

4.1.1. CAT bond-specific variables

Expected loss (EL): Previous studies (Papachristou, 2011; Galeotti et al., 2013, etc.) have already confirmed that "expected loss" is an essential driver of the CAT bond spread. EL is estimated by different natural catastrophe risk models of specialized firms, such as Applied Insurance Research Worldwide (AIR), Eqecat Inc. (EQECAT), and Risk Management Solutions Inc. (RMS). It is defined as the probability of first dollar loss (PFL) multiplied by conditional expected loss (CEL), where the value of PFL presents the frequency of a loss, and the value of CEL represents the severity of a loss. Given the same PFL level, which means catastrophes have an equal probability of happening, investors require a higher return from a CAT bond that has a higher CEL and vice versa.

Trigger (Trig): There are two main trigger types, indemnity and non-indemnity, that determine CAT bonds' reductions in payments. Indemnity triggers are based on the actual catastrophe loss incurred by the sponsor, and so possible information asymmetries between the transaction partners expose investors to moral hazard (Lee and Yu, 2007). Non-indemnity triggers can reduce and eliminate moral hazard, but they can also incur basis risk for sponsors without perfect correlations between actual and reference catastrophe losses (Cummins et al., 2004). We define a dummy variable Trig that equals one if a CAT bond relies on an indemnity trigger and zero otherwise.

Rating (IG): It is well-known that a bond rating can proxy for the ease of bond trading activities and has a significant effect on its spread. We treat the rating dummy variable IG as one for investment grade and zero for high-yield CAT bonds.

Peril (Wind; Eqk): In our sample, hurricanes, windstorms, and typhoons are always referred to as strong wind activities in the U.S., Europe, and Japan, respectively. We set Wind and Eqk to be the peril dummy variables. If a CAT bond insures hurricanes, windstorms, and typhoons, then the dummy Wind equals one and zero otherwise. If a CAT bond insures earthquakes, then the dummy Eqk equals one.

Covered territory (US; EU; JP; Multiterritory): There are three main territories (U.S., Europe, and Japan), and so we set up three dummy variables: US, EU, and JP. When a territory does not belong to these three variables, US, EU, and JP equal zero. If the territory of a CAT bond covers at least two regions among US, EU, JP, as well as other regions, then the dummy variable Multiterritory equals one.

4.1.2. Macroeconomic variables

Previous studies find that some macroeconomic factors, including capital markets and reinsurance cycles, can determine CAT bond spreads.

S&P 500 return (SP 500): We use the SP 500 return to measure the effect of stock markets on CAT bond spreads, because Gürtler et al. (2016) find evidence that CAT bonds are not zero-beta securities.

Corporate bond spreads (BBspread): There is a contagion effect between corporate bonds and CAT bonds, meaning investors always perceive that CAT and corporate bonds with the same rating carry a similar risk. As most CAT bonds have a BB rating, we use the BB corporate bond spread (BBspread) to capture the above contagion effects.

Reinsurance cycle (RI): CAT bonds can be considered as an alternative to traditional reinsurance (Cummins and Trainar, 2009; Finken and Laux, 2009). We use the change in the Guy Carpenter Global Property Rate on Line Index (RI) to measure the impact of the reinsurance cycle on CAT bond spreads. This index is the proprietary index of global property catastrophe reinsurance Rate-on-Line movements, surveyed annually by Guy Carpenter & Company Ltd. since 1990.

[9] Lane Financial LLC: http://www.lanefinancialllc.com/index.php.
Artemis: http://www.artemis.bm/deal_directory/.

Table 2
Summary statistics: CAT bond and macroeconomic variables.

	Obs	Mean	Std. Dev.	Min	Max
Panel A: CAT bond variables					
CATspread1 (bps)	464	810.073	559.279	65	4920
CATspread2 (bps)	4,751	717.369	559.968	62	7595
Expected Loss (EL) (bps)	464	214.424	207.209	0	1306
Amount ($ million)	464	125.838	119.422	1.8	1500
Maturity (MT) (months)	464	36.1379	11.845	5	61
Time to Maturity (TTM) (months)	4,751	17.446	12.229	0	60
No. of perils (Nperils)	464	1.927	1.276	1	8
Panel B: Macroeconomic variables					
S&P 500 Return (bps)	54	47.194	254.9665	-646.638	472.295
Corp. Spread (BBspread) (bps)	54	394.630	174.602	189	1145.333
Reins. Index (RI) (bps)	15	18.667	1422.593	-1120	3660

4.2. Descriptive statistics

Table 2 shows the summary statistics of CAT bond-specific variables and macroeconomic variables. There are 464 CAT bond contracts in our sample. In Panel A of the CAT bond-specific variables, the mean values of the CAT bond spread over LIBOR in the primary market (CATspread1) and the secondary market (CATspread2) are 810.07bps and 717.37bps, respectively. The average mean of expected loss (EL) is 214.42bps.

CAT bonds have an average maturity (MT) of about three years and an average bond size (Amount) of $125.84 million. The average number of perils (Nperils) is 1.93, indicating bonds with multiple perils are more popular. Panel B includes quarterly observations of capital market variables (S&P 500 index returns and spreads of U.S. BB corporate bonds) and yearly changes in the Guy Carpenter Global Property Rate on Line Index (RI). The mean of quarterly spreads for BB-rated corporate bonds is 394.63bps. We note that the mean of CAT bond spreads, either in the primary market or the secondary market, is larger than the mean of BB corporate bond spreads.

5. Empirical analysis and discussion

We use both the liquidity-sorted portfolio approach and the entire sample approach in our empirical investigation.

5.1. Liquidity-sorted portfolio approach

We divide the secondary market data into five portfolios for all eight liquidity proxies, except for the Sponsor proxy, which is a dummy variable.[10] Table 3 shows the summary statistics of the mean value of CAT bond spreads (CATspread2) and the eight liquidity proxies for these 37 portfolios over the full sample period. We observe that CAT bond spreads increase monotonically from the hypothesized most liquid portfolio (portfolio 1) to the hypothesized most illiquid portfolio (portfolio 5) for the liquidity proxies of Amount, Nperils, and Volatility, which is consistent with our liquidity hypotheses (H1, H3, and H6). However, CAT bond spreads (CATspread2) in portfolios for the other five proxies do not show a clear monotonic pattern.

We use regression (1) to test the effect of liquidity on CAT bond spreads for each liquidity-sorted portfolio after controlling for other sources of risk.

$$\begin{aligned} ln(CATspread2_{it}^{kj}) &= \beta_0^{kj} + \beta_1^{kj}EL_i + \beta_2^{kj}Trig_i + \beta_3^{kj}IG_i + \beta_4^{kj}Wind_i + \beta_5^{kj}Eqk_i + \beta_6^{kj}Multiterritory_i + \beta_7^{kj}US_i + \beta_8^{kj}EU_i + \beta_9^{kj}JP_i + \beta_{10}^{kj}SP500_t + \beta_{11}^{kj} \\ &RI_t + \beta_{12}^{kj}BBspread_t + \beta_{13}^{kj}Year\,fixed\,effects + \varepsilon_{it}^{kj} \end{aligned} \quad (1)$$

$k = 1, 2, \ldots, 5, j = 1, 2, \ldots, 8$

We take logs of CAT bond spreads to control for heteroscedasticity. For each proxy j, we examine the differences of the intercepts and the R-squared among the five regressions. In regression (1), intercept term, ${\beta_0}^{kj}$, is the portfolio-specific liquidity premium, and R-squared measures the proportion of the variation in CAT bond spreads that is explained by regression (1) without a liquidity proxy for each liquidity-sorted portfolio. If proxy j is an appropriate measure of CAT bond liquidity, then the portfolio-specific liquidity premium (${\beta_0}^{kj}$) would be increasing monotonically and R-squared would be decreasing monotonically from the most liquid portfolio (portfolio 1) to the most illiquid portfolio (portfolio 5).

Following earlier research, we include other sources of risk such as expected losses (EL), trigger (Trig), bond rating (IG), etc. as

[10] Four liquidity proxies (Amount, Sponsor, MT, and Nperils) are CAT bond-specific variables of the primary market that are not affected by time, and so we create portfolios for these four proxies based on the primary market data.

Table 3
Mean values of CAT bond spreads and liquidity proxies across 5 liquidity-sorted portfolios.

Mean Values of CATspread2

Liquidity Proxies	Portfolio 1	Portfolio 2	Portfolio 3	Portfolio 4	Portfolio 5
Amount	489.61	618.79	738.23	847.54	856.26
Sponsor	826.11	671.76			
Nperils	596.28	606.41	658.22	764.65	989.1
MT	1028.79	716.34	769.42	641.28	566.23
TTM	700.13	757.07	758.72	705.33	649.59
Volatility	353.24	534.75	650.04	769.66	1279.53
Dispersion	784.61	727.74	685.61	614.41	774.4
DispersionE	616.81	774.99	744.86	705.74	744.55

Mean Values of Liquidity Proxies

Liquidity Proxies	Portfolio 1	Portfolio 2	Portfolio 3	Portfolio 4	Portfolio 5
Amount	300.58	158.91	98.74	61.23	22.14
Sponsor	1.00	0.00			
Nperils	1.00	1.00	1.61	2.05	4.14
MT	19.64	35.02	36.00	41.76	52.05
TTM	4.39	12.26	20.47	28.74	40.67
Volatility	44.82	100.75	159.99	233.90	499.32
Dispersion	0.02	0.09	0.19	0.34	0.92
DispersionE	0.96	1.99	3.01	4.71	34.93

Portfolio 1 contains the hypothesized most liquid CAT bonds, and portfolio 5 contains the most illiquid CAT bonds. CATspread2 is the mean of CAT bond spreads in the secondary market.

control variables in our empirical regressions.[11] If the trigger type of a CAT bond is indemnity, then a dummy variable Trig equals one and zero otherwise. A dummy IG is one when CAT bonds have an investment grade rating and is zero for high-yield CAT bonds. Some dummy variables are related to the covered territory and reference peril as described in section 3.2.1 (Wind; Eqk; Multiterritory; US; EU; JP). We use the S&P 500 quarterly returns and BB levels of U.S. corporate bond spreads (BBspread) to represent the impact of capital markets on CAT bond spreads. Finally, we add the change in the Guy Carpenter Global Property Rate on Line Index (RI) to measure the reinsurance cycle and to control for the interrelationship between CAT bonds and reinsurance.

Table 4 shows the intercept term and R-squared of regression (1) for all liquidity-sorted portfolios. The intercept terms and R-squared of regression (1) for the four proxies, Amount, MT, TTM, and DispersionE, do not display a monotonic pattern from the most liquid portfolio (portfolio 1) to the most illiquid portfolio (portfolio 5). Given the increasing pattern of the intercept terms of regression (1), the R-squared values of regression (1) for proxy Nperils do not exhibit a decreasing pattern from portfolios 1 to 5. At the same time, the intercept terms and R-squared of regression (1) for proxy Sponsor both decrease from portfolios 1 to 5. In the Dispersion column of Table 4, R-squared decreases when liquidity risk, as measured by the Dispersion proxy, becomes larger. The intercept term in the most illiquid portfolio of the Dispersion proxy is 38.56 and more than seven times larger than that of the four other portfolios of the Dispersion proxy, but it is not significant. Thus, we cannot conclude that Nperils, Sponsor, and Dispersion capture the liquidity effect on CAT bond spreads based on the liquidity-sorted portfolios analysis. In Table 4 we do confirm that the variable Volatility is an effective liquidity measure for CAT bonds, because all intercepts in the five portfolios of the volatility liquidity measure are around 5, but the R-squared of regression decreases monotonically from 0.727 in the most liquid portfolio (portfolio 1) to 0.432 in the most illiquid portfolio (portfolio 5).

5.2. *Entire-sample approach*

The above liquidity-sorted portfolio analysis can be affected by the number of portfolios selected and does not simultaneously examine the impacts of various liquidity proxies on CAT bond spreads. Thus, we use the entire-sample analysis as the second approach to overcome the shortcomings of liquidity-sorted portfolio analysis and to test if some liquidity proxies work better than others. We first run regression (1) with our entire sample from 2002: Q2 to 2016: Q1 without any of the eight liquidity proxies as our benchmark model. Next, we respectively add the eight liquidity proxies ($Liquidity_{it}^{j}$) into the benchmark model to run the following regression:

[11] CAT bond payments are usually made through an embedded swap contract of the SPV to immunize the insurer and the investors from interest rate risk. The fixed investment returns on safe, short-term securities held in the trust account are usually swapped for floating returns based on LIBOR or some other some widely accepted index. CAT bonds are fully collateralized instruments that can eliminate concerns about credit risk. Thus, we do not incorporate credit risk and interest rate risk as risk sources of CAT bonds.

$$\ln(CATspread_{it}) = \beta_0 + \beta_1 EL_i + \beta_2 Trig_i + \beta_3 IG_i + \beta_4 Wind_i + \beta_5 Eqk_i + \beta_6 Multiterritory_i + \beta_7 US_i + \beta_8 EU_i + \beta_9 JP_i + \beta_{10} Year\ fixed\ effects + \beta_{11} RI_t + \beta_{12} BBspread_t + \beta_{13} SP500_t + \beta_{14}^j Liquidity_{it}^j + \varepsilon_i \quad (2)$$

Here, $Liquidity_{it}^j$ refers to the eight liquidity proxies of CAT bonds. If the coefficient of liquidity proxy j (β_{14}^j) is significant, then liquidity proxy j is an effective liquidity proxy and can measure the liquidity effect on CAT bond spreads.

Table 5 shows that the four coefficients of liquidity proxies, TTM, Volatility, Dispersion, and DispersionE, are significant. In line with the liquidity hypotheses (H5, H6, H7, and H8), these four liquidity proxies have significantly positive impacts on CAT bond

Table 4
Liquidity-sorted portfolios analysis.

	Amount			Sponsor		
Portfolio	Intercept	R-squared	N	Intercept	R-squared	N
1	5.958** (0.51)	0.597	807	5.352** (0.12)	0.759	1,404
2	5.396** (0.20)	0.677	1,009			
3	4.996** (0.14)	0.540	978			
4	5.190** (0.11)	0.677	1,026			
5	4.996** (0.17)	0.804	931	5.250** (0.10)	0.614	3,347

	Nperils			MT		
Portfolio	Intercept	R-squared	N	Intercept	R-squared	N
1	4.998** (0.16)	0.685	936	5.116** (0.22)	0.69	578
2	4.960** (0.11)	0.707	915	5.131** (0.16)	0.632	969
3	5.246** (0.19)	0.716	1,003	5.133** (0.14)	0.697	1,113
4	5.854** (0.20)	0.526	1,075	5.050** (0.15)	0.695	1,054
5	6.026** (0.20)	0.718	822	5.007** (0.17)	0.661	1,037

	TTM			Volatility		
Portfolio	Intercept	R-squared	N	Intercept	R-squared	N
1	29.671** (0.01)	0.483	895	5.396** (0.20)	0.727	951
2	47.730** (0.00)	0.757	950	5.162** (0.09)	0.716	950
3	5.007** (0.00)	0.728	950	5.315** (0.11)	0.638	950
4	5.158** (0.00)	0.756	950	5.370** (0.14)	0.561	950
5	5.286** 0.00	0.768	950	5.914** (0.24)	0.432	950

	Dispersion			DispersionE		
Portfolio	Intercept	R-squared	N	Intercept	R-squared	N
1	5.223** (0.08)	0.822	951	15.15* (7.29)	0.736	951
2	5.253** (0.09)	0.822	950	5.404** (0.06)	0.879	950
3	5.224** (0.10)	0.806	950	5.360** (0.05)	0.903	950

(*continued on next page*)

Table 4 (*continued*)

	Dispersion			DispersionE		
Portfolio	Intercept	R-squared	N	Intercept	R-squared	N
4	5.063** (0.10)	0.753	950	5.606** (0.11)	0.911	950
5	38.56 (26.97)	0.421	950	5.127** (0.18)	0.705	950

We order all bonds in the sample by their value of liquidity proxy j and create five mutually exclusive portfolios for each proxy j. The sort order is chosen such that portfolio 1 contains the bonds that are supposed to be the most liquid and portfolio 5 contains the most illiquid. The four liquidity proxies (Amount, Sponsor, MT, and Nperils) are CAT bond-specific variables that are not affected by time, and so we create portfolios for these 4 proxies based on the primary market data. We run regression (1):

$$\ln(CATspread2_{it}^{kj}) = \beta_0^{kj} + \beta_1^{kj} EL_i + \beta_2^{kj} Trig_i + \beta_3^{kj} IG_i + \beta_4^{kj} Wind_i + \beta_5^{kj} Eqk_i + \beta_6^{kj} Multiterritory_i + \beta_7^{kj} US_i + \beta_8^{kj} EU_i + \beta_9^{kj} JP_i + \beta_{10}^{kj} SP500_t + \beta_{11}^{kj} RI_t + \beta_{12}^{kj} BBspread_t + \beta_{13}^{kj} Year\,fixed\,effects + \varepsilon_{it}^{kj} \quad (1)$$

Table 4 shows the constant term and R-squared of regression (1) for all liquidity-sorted portfolios. Clustered standard errors are in parentheses.
** $p < 0.01$.
* $p < 0.05$.

spreads. CAT bonds with a shorter time to maturity have lower bond spreads, whereas a CAT bond's higher yield volatility implies a higher spread. Moreover, investors demand higher liquidity premiums for CAT bonds with larger information uncertainty (Dispersion and DispersionE). Based on the above analysis, we can consider TTM, Volatility, Dispersion, and DispersionE as effective liquidity measures. Our empirical results provide evidence that investors demand a liquidity risk premium in the CAT bond markets, and that the four liquidity proxies are priced into CAT bond spreads.

Given these four liquidity proxies identified in the above analysis, a natural question to ask is whether these four proxies are equally suited to proxy CAT bond liquidity or if some proxies work better than others. For each combination (j, k) of liquidity proxies, we estimate the following regression (3):

$$\ln(CATspread_{it}) = \beta_0 + \beta_1 EL_i + \beta_2 Trig_i + \beta_3 IG_i + \beta_4 Wind_i + \beta_5 Eqk_i + \beta_6 Multiterritory_i + \beta_7 US_i + \beta_8 EU_i + \beta_9 JP_i + \beta_{10} Year\,fixed\,effects + \beta_{11} RI_t + \beta_{12} BBspread_t + \beta_{13} SP500_t + \beta_{14} Liquidity_{it}^{j} + \beta_{15} liquidity_{it}^{jk} + \varepsilon_i \quad (3)$$

If β_{15} is significant, then we say that liquidity proxy k adds explanatory power to proxy j. We repeat this procedure for all possible combinations and count the number of times a liquidity proxy adds power to another proxy. The results of Model 7-8 in Table 6 show that the coefficient of DispersionE is not significant when we put both Dispersion and DispersionE into regression (3).

When we include the four liquidity proxies in the same regression (Model 5-6-7-8), three proxies (TTM, Volatility, and Dispersion) still maintain a significantly positive impact on CAT bond spreads, but the coefficient of DispersionE is not significant. Thus, Dispersion (from the primary market yield) works better than DispersionE (from the expert forecast) as a CAT bond liquidity measure. The other three liquidity proxies, time to maturity (TTM), yield volatility (Volatility), and yield dispersion (Dispersion), have significant coefficients in all comparison tests. We conclude that these three are the most effective CAT bond liquidity proxies that best capture the liquidity effect on CAT bond spreads in different dimensions.

We finally add the three most effective proxies for CAT bond liquidity (TTM, Volatility, and Dispersion) into our benchmark model (Model 0), which considers other sources of risk than illiquidity, to get Model 5-6-7. We measure the liquidity premium of CAT bonds by the difference of the predicted values of Model 5-6-7 with three liquidity proxies and the predicted values of the benchmark model (Model 0) without these three proxies in Table 6. We find that the mean value of the liquidity premium based on our three liquidity proxies is 67.57bps, indicating that these three liquidity proxies on average account for 9.42% (67.57/717.37) of the secondary market spreads.

Fig. 2 shows the quarterly averages of CAT bond spreads and liquidity premium over the sample period. After Hurricane Katrina in August 2005, the average liquidity risk premium rises from 35.55bps in 2005: Q3 to 142.47bps in 2006: Q3. The 2008 financial crisis, triggered by the bankruptcy of Lehman Brothers in September 2008, also significantly affects the liquidity premium. The premium hits 210.67bps in 2008: Q4 and peaks at 219.46bps in 2009: Q1. During these two periods, the liquidity premium accounts for over 30% of the CAT bond spreads. As the market continues to grow and develop, the average liquidity premium exhibits a declining trend after the 2008 financial crisis.

5.3. Robustness check

In this section we add time to maturity (TTM), yield volatility (Volatility), and yield dispersion (Dispersion) into regression (2) to perform several robustness checks as to the validity of the above three CAT bond liquidity proxies. In addition to the OLS model

Table 5
Entire-sample analysis.

	ln(CATspread2)				
	Model 0	Model 1	Model 2	Model 3	Model 4
Controlling other risks	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y
Constant	5.097**	5.131**	5.099**	5.156**	5.109**
	(0.061)	(0.067)	(0.066)	(0.092)	(0.065)
Amount		0.000			
		(0.000)			
Sponsor			-0.001		
			(0.002)		
Nperils				-0.004	
				(0.045)	
MT					0.014
					(0.027)
Observations	4,751	4,751	4,751	4,751	4,751
R-squared	0.656	0.657	0.656	0.657	0.663
	ln(CATspread2)				
	Model 0	Model 5	Model 6	Model 7	Model 8
Controlling other risks	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y
Constant	5.097**	5.008**	5.182**	5.140**	5.092**
	(0.061)	(0.000)	(0.060)	(0.058)	(0.062)
TTM		0.003**			
		(0.000)			
Volatility			0.001**		
			(0.000)		
Dispersion				0.173**	
				(0.045)	
DispersionE					0.001*
					(0.000)
Observations		4,751	4,738	4,751	4,696
R-squared		0.6601	0.683	0.674	0.664

We conduct the following regression (2):

$$\ln(CATspread2_{it}) = \beta_0 + \beta_1 EL_i + \beta_2 Trig_i + \beta_3 IG_i + \beta_4 Wind_i + \beta_5 Eqk_i + \beta_6 Multiterritory_i + \beta_7 US_i + \beta_8 EU_i + \beta_9 JP_i + \beta_{10} Year\,fixed\,effects + \beta_{11} RI_t + \beta_{12} BBspread_t + \beta_{13} SP500_t + \beta_{14}^{j} Liquidity_{it}^{j} + \varepsilon_i \quad (2)$$

$Liquidity_{it}^{j}$ refers to the 8 liquidity proxies of CAT bonds. Table 5 shows the constant term and coefficients of liquidity proxy j of regression (2). Clustered standard errors are in parentheses.

** $p < 0.01$.
* $p < 0.05$.

applied in the above empirical analysis, we consider random effects (Model RE) and fixed effects (Model FE) as robustness checks in Panel A of Table 7. Panel B of Table 7 shows the robustness check results of the wind, earthquake, and multiperil subsamples. We find that the coefficients of our three CAT bond liquidity proxies are significantly positive in all robustness checks, and so time to maturity (TTM), yield volatility (Volatility), and yield dispersion (Dispersion) are indeed robust liquidity proxies for CAT bond markets.

5.4. Implications for investment management

Our empirical results have some practical implications for investment management and risk management. Although the average liquidity premium accounts for less than 10% of CAT bond spreads, the CAT bond liquidity premium is still higher than the corporate bond liquidity premium of a similar risk class by about 35bps during the pre-crisis period (from 2005: Q1 to 2007: Q1). We also note that the liquidity premium of CAT bonds increases significantly after extreme catastrophe events, and that both CAT bond and

Table 6
Comparison test.

ln(CATspread2)					
	Model 0	Model 5-6	Model 5-7	Model 5-8	Model 6-7
Controlling other risks	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y
Constant	5.097**	5.083**	5.005**	4.993**	5.195**
	(0.061)	(0.060)	(0.059)	(0.063)	(0.058)
TTM		0.004**	0.005**	0.004**	
		(0.001)	(0.001)	(0.001)	
Volatility		0.001**			0.001**
		(0.000)			(0.000)
Dispersion			0.202**		0.114**
			(0.049)		(0.037)
DispersionE				0.001*	
				(0.000)	
Observations	4,751	4,738	4,751	4,696	4,738
R-squared	0.656	0.689	0.687	0.671	0.69

	ln(CATspread2)				
	Model 0	Model 6-8	Model 7-8	Model 5-6-7-8	Model 5-6-7
Controlling other risks	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y
Constant	5.097**	5.177**	5.122**	5.048**	5.068**
	(0.061)	(0.061)	(0.058)	(0.059)	(0.058)
TTM				0.005**	0.005**
				(0.001)	(0.001)
Volatility		0.001**		0.001**	0.001**
		(0.000)		(0.000)	(0.000)
Dispersion			0.179**	0.139**	0.145**
			(0.052)	(0.051)	(0.040)
DispersionE		0.001*	0.000	0.000	
		(0.000)	(0.001)	(0.001)	
Observations	4,751	4,683	4,696	4,683	4,738
R-squared	0.656	0.69	0.679	0.704	0.699

For each combination (j, k) of liquidity proxies, we estimate the following regression (3):

$$\ln(CATspread2_{it}) = \beta_0 + \beta_1 EL_i + \beta_2 Trig_i + \beta_3 IG_i + \beta_4 Wind_i + \beta_5 Eqk_i + \beta_6 Multiterritory_i + \beta_7 US_i + \beta_8 EU_i + \beta_9 JP_i + \beta_{10} Year\ fixed\ effects + \beta_{11} RI_t + \beta_{12} BBspread_t + \beta_{13} SP500_t + \beta_{14} Liquidity_{it}^{j} + \beta_{15} liquidity_{it}^{jk} + \varepsilon_i \quad (3)$$

Table 6 shows the constant term and coefficients of the liquidity proxy of regression (3). Clustered standard errors are in parentheses.
** $p < 0.01$.
* $p < 0.05$.

corporate bond liquidity premiums rise to the same high level of 123bps during the 2008 financial crisis period.[12] Thus, the CAT bond market exposes investors to the same level of liquidity risk as corporate bond markets during the time of a financial crisis.

6. Conclusion

Catastrophe bonds are one of the most successful securitization structures in the insurance and reinsurance markets over the past two decades and have high-yield spreads. Considering the complexity of CAT bond contracts and the nature of OTC market transactions, liquidity has always been a potential explanation for observed high spreads. However, previous studies provide neither a comprehensive analysis of the CAT bond market's liquidity nor any empirical evidence for the liquidity effect on CAT bond spreads. This research therefore identifies the liquidity proxies in the CAT bond market to measure the contribution of liquidity premium to the total CAT bond spread and the contribution of premium associated with other risk natures of CAT bonds.

This research thus considers eight possible proxies based on the literature of corporate bonds to measure CAT bond liquidity and

[12] Dick-Nielsen et al. (2012) estimate that the liquidity premium for speculative-grade corporate bonds is about 45bps from 2005: Q1 to 2007: Q1, but we find that CAT bonds have about 80.74bps of liquidity premium during the same period. They also show that the liquidity component for speculative-grade corporate bonds hit 123.6bps during the financial crisis period (from 2007: Q2 to 2009: Q2).

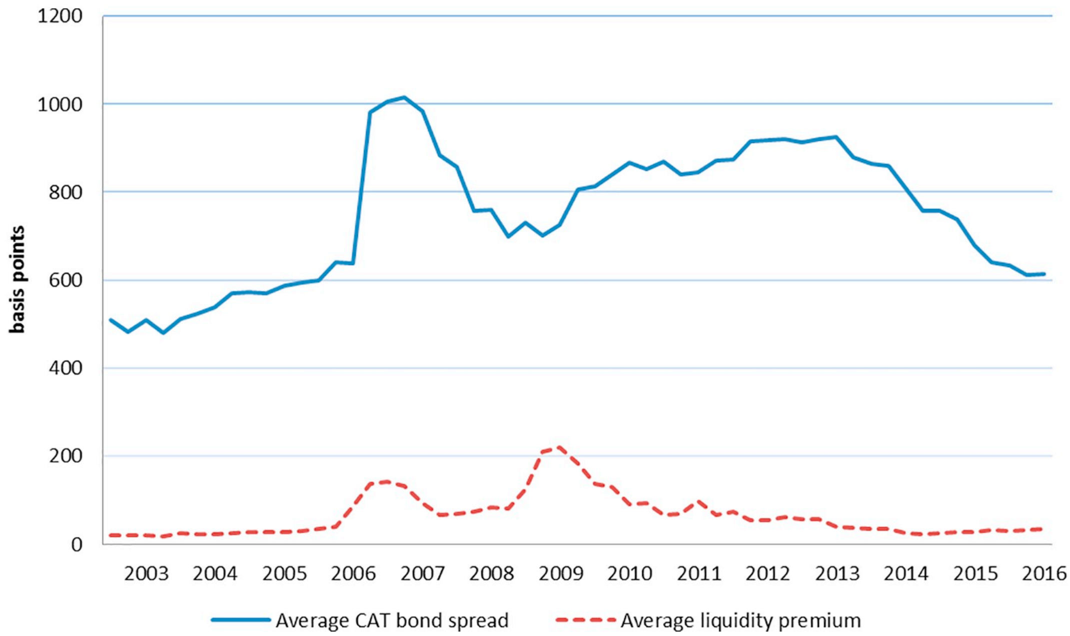

Fig. 2. Quarterly averages of CAT bond spreads and liquidity premiums.

to examine whether a liquidity premium is present, and if so, how much of it is priced into the spreads of CAT bonds. We collect a comprehensive dataset of CAT bonds in both primary and secondary markets from 2002: Q2 to 2016: Q1. Our findings support the hypothesis that liquidity is priced in the CAT bond market in four out of eight liquidity proxies, including time to maturity, yield volatility, yield dispersion from the primary market, and yield spread dispersion from the expert forecast. Although the yield spread dispersion from the expert forecast (DispersionE) is positive and significantly related to CAT bond spreads, a further comparison test between liquidity proxies finds that the yield spread dispersion from the expert forecast (DispersionE) does not add explanatory

Table 7
Robustness check.

	Panel A		Panel B		
	Model RE	Model FE	Model Wind	Model Eqk	Model Multiperil
Controlling other risks	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y
Constant	5.082***	5.793**	5.206**	5.181**	5.478**
	(0.061)	(0.035)	(0.071)	(0.068)	(0.140)
TTM	0.007**	0.009**	0.005**	0.005**	0.007**
	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)
Volatility	0.0003**	-	0.001**	0.0004**	0.001**
	(0.000)	-	(0.000)	(0.000)	(0.000)
Dispersion	0.211**	0.221**	0.121**	0.175**	0.154**
	(0.027)	(0.026)	(0.042)	(0.046)	(0.046)
Observations	4,738	4,738	3,943	3,000	2,217
R-squared	0.688	0.406	0.657	0.760	0.695

We add the three liquidity proxies of time to maturity (TTM), yield volatility (Volatility), and yield dispersion (Dispersion) into regression (2) to execute the following regression:

$$\ln(CATspread2_{it}) = \beta_0 + \beta_1 EL_i + \beta_2 Trig_i + \beta_3 IG_i + \beta_4 Wind_i + \beta_5 Eqk_i + \beta_6 Multiterritory_i + \beta_7 US_i + \beta_8 EU_i + \beta_9 JP_i + \beta_{10} Year\ fixed\ effects + \beta_{11} RI_t + \beta_{12} BBspread_t + \beta_{13} SP500_t + \beta_{14} TTM_{it} + \beta_{15} Volatility_i + \beta_{15} Dispersion_{it} + \varepsilon_i$$

Table 7 reports the constant term and coefficients of liquidity proxies (TTM, Volatility, and Dispersion) of the above regression. Model RE and Model FE in Panel A are random effect and fixed effect models, respectively. R-squared in Model RE is overall-R^2, and R-squared in Model FE is within-R^2. Panel B shows the robustness check results of wind, earthquake, and multiperil subsamples. Clustered standard errors are in parentheses.

** $p < 0.01$.
* $p < 0.05$.

power to yield spread dispersion from the primary market (Dispersion). We thus conclude that TTM, Volatility, and Dispersion are the three most effective proxies of CAT bonds to measure the liquidity effect on CAT bond spreads.

The empirical results of this study shed light on some important practical implications for investors who choose CAT bonds as alternative investments. This study identifies the three most effective proxies for practitioners and academics to understand liquidity risk in the CAT bond market. Based on these three liquidity proxies, for the first time, we are able to estimate the liquidity premium of CAT bonds. The average CAT bond liquidity premium is 67.57bps and constitutes 9.42% of the 717.37bps in CAT bond spreads in the secondary market. The more significant part of the high spreads, 90.58%, is attributed to other risk natures in CAT bonds. This evidence indicates that the liquidity premium on average is only a small portion of the high-yield spreads of CAT bond markets over the past 15 years, whereas the liquidity premium is higher than that of corporate bonds of a similar risk class. It is also noteworthy that the liquidity premium of CAT bonds increases dramatically after the occurrences of severe natural catastrophes and for the 2008 financial crisis. During these two periods, the liquidity premium accounts for over 30% of the CAT bond spreads. As the market continues to grow and develop, the average liquidity risk premium exhibits a declining trend after the 2008 financial crisis. Regarding the diversification feature of CAT bonds, even though CAT risk is generally unrelated to other financial assets, our results suggest that CAT bond markets are exposed to considerable liquidity risk following extreme catastrophe events and during a financial crisis.

References

Alexander, G.J., Edwards, A.K., Ferri, M.G., 2000. The determinants of trading volume of high-yield corporate bonds. J. Financ. Markets 3 (2), 177–204.

Amihud, Y., Mendelson, H., 1991. Liquidity, maturity, and the yields on US Treasury securities. J. Financ. 46 (4), 1411–1425.

Arrow, K.J., Forsythe, R., Gorham, M., Hahn, R., Hanson, R., Ledyard, J.O., ... Neumann, G.R., 2008. Economics: the promise of prediction markets. Science 320 (5878), 877–878.

Bao, J., Pan, J., Wang, J., 2011. The illiquidity of corporate bonds. J. Financ. 66 (3), 911–946.

Braun, A., 2016. Pricing in the primary market for cat bonds: new empirical evidence. J. Risk Insurance 83 (4), 811–847.

Chang, C.-C., Yang, J.-W., Yu, M.-T., 2018. Hurricane risk management with climate and CO_2 indices. J. Risk Insurance 85 (3), 695–720.

Chen, L., Lesmond, D.A., Wei, J., 2007. Corporate yield spreads and bond liquidity. J. Financ. 62 (1), 119–149.

Chen, X., Doerpinghaus, H., Lin, B.X., Yu, T., 2008. Catastrophic losses and insurer profitability: evidence from 9/11. J. Risk Insurance 75 (1), 39–62.

Chen, N.-W., Liang, H.-Y., Yu, M.-T., 2018. Asset diversification and bank performance: evidence from three Asian Countries with a dual banking system. Pacific-Basin Financ. J. 52, 40–53.

Cummins, J.D., 2012. CAT bonds and other risk-linked securities: product design and evolution of the market. Geneva Rep. 39.

Cummins, J.D., Trainar, P., 2009. Securitization, insurance, and reinsurance. J. Risk Insurance 76 (3), 463–492.

Cummins, J.D., Lalonde, D., Phillips, R.D., 2004. The basis risk of catastrophic-loss index securities. J. Financ. Econ. 71 (1), 77–111.

Dick-Nielsen, J., Feldhütter, P., Lando, D., 2012. Corporate bond liquidity before and after the onset of the subprime crisis. J. Financ. Econ. 103 (3), 471–492.

Dieckmann, S., 2019. A consumption-based evaluation of the cat bond market. Adv. Pacific Basin Bus. Econ. Financ. 7 forthcoming.

Edwards, A.K., Harris, L.E., Piwowar, M.S., 2007. Corporate bond market transaction costs and transparency. J. Financ. 62 (3), 1421–1451.

Ennis, R.M., 2008. Prediction markets. Financ. Anal. J. 64 (5), 8–10.

Finken, S., Laux, C., 2009. Catastrophe bonds and reinsurance: the competitive effect of information-insensitive triggers. J. Risk Insurance 76 (3), 579–605.

Fisher, L., 1959. Determinants of risk premiums on corporate bonds. J. Political Econ. 217–237.

Galeotti, M., Gürtler, M., Winkelvos, C., 2013. Accuracy of premium calculation models for CAT bonds—an empirical analysis. J. Risk Insurance 80 (2), 401–421.

Gürtler, M., Hibbeln, M., Winkelvos, C., 2016. The impact of the financial crisis and natural catastrophes on CAT bonds. J. Risk Insurance 83 (3), 579–612.

Guy Carpenter, 2006. The Catastrophe Bond Market at Year-End 2005: Ripple Effects from Record Storms. Guy Carpenter & Company, New York.

Hong, G., Warga, A., 2000. An empirical study of bond market transactions. Financ. Anal. J. 56 (2), 32–46.

Hood, M., Kamesaka, A., Nofsinger, J., Tamura, T., 2013. Investor response to a natural disaster: Evidence from Japan's 2011 earthquake. Pacific-Basin Financ. J. 25, 240–252.

Houweling, P., Mentink, A., Vorst, T., 2005. Comparing possible proxies of corporate bond liquidity. J. Banking Financ. 29 (6), 1331–1358.

Lee, J.-P., Yu, M.-T., 2002. Pricing default-risky CAT bonds with moral hazard and basis risk. J. Risk Insurance 69 (1), 25–44.

Lee, J.-P., Yu, M.-T., 2007. Valuation of catastrophe reinsurance with catastrophe bonds. Insurance Math. Econ. 41 (2), 264–278.

Li, X.D., Jiao, Y., Yu, M.-T., Zhao, Y., 2019. Founders and the decision of Chinese dual-class IPOs in the U.S. Pacific-Basin Financ. J. 54 available online 31 October 2018, (article in press).

Lo, J.-L., Shih, P.-T., Wang, Y.-H., Yu, M.-T., 2019. VIX derivatives: valuation models and empirical evidence. Pacific-Basin Financ. J. 53, 1–21.

Papachristou, D., 2011. Statistical analysis of the spreads of catastrophe bonds at the time of issue. ASTIN Bull. 41 (1), 251–277.

Sarig, O., Warga, A., 1989. Bond price data and bond market liquidity. J. Financ. Quant. Anal. 24 (03), 367–378.

Schestag, R., Schuster, P., Uhrig-Homburg, M., 2016. Measuring liquidity in bond markets. Rev. Financ. Stud. 29 (5), 1170–1219.

Shulman, J., Bayless, M., Price, K., 1993. Marketability and default influences on the yield premia of speculative-grade debt. Financ. Manag. 132–141.

Tychon, P., Vannetelbosch, V., 2002. Debt valuation and marketability risk. Working paper. Université Catholique de Louvain.

Wolfers, J., Zitzewitz, E., 2004. Prediction markets. J. Econ. Perspect. 18 (2), 107–126.

Zhao, Y., Yu, M.-T., 2018. Prediction markets for catastrophe risk: evidence from catastrophe bond markets. In: 2018 Annual Meeting - Financial Management Association.