CLIMATE RISK AND CATASTROPHE BOND PRICES

[1]CHIA-CHIEN CHANG, [2]MIN-THE YU, [3]YANG ZHAO

[1]Department of Finance and Information, National Kaohsiung University of Science and Technology, Taiwan
[2]Department of Finance, National Chiao Tung University and NCCU-RIRC, Taiwan
[3]Institute of Finance, National Chiao Tung University, Taiwan
E-mail: [1]cchiac@nkust.edu.tw, [2]mtyu@nctu.edu.tw, [3]zy0383905@foxmail.com

Abstract - This research analyzes how the fluctuations of climate cycles and carbon dioxide (CO_2) levels affect catastrophe (CAT) bond prices in primary and secondary markets. Our results uncovera significant link between the primary and secondary markets where by CAT bond prices in the secondary market incorporate both explained and idiosyncratic information in the primary market. More importantly, CAT bond prices in the secondary market reveal risk information from the six climate cycles and CO_2 variations, but not so in the primary market. Thus, the secondary market with more information helps market prices reveal private information and improves price quality. Overall, our empirical evidence also supports that CAT bond markets are a successful financing scheme for CAT risk in terms of timely reflecting the risk information of climate cycles and carbon dioxide for CAT bond prices in secondary markets.

Keywords - Climate Risk, CAT bond prices, Price quality, Primary market, Secondary market.

I. INTRODUCTION

Catastrophe (CAT) bonds, the most successful non-traditional risk hedging instrument, help resolve reinsurance market inefficiencies and transfercatastrophe risk in insurance markets directly to securities markets (e.g., Cummins and Weiss (2009)). In fact, the CAT bond market continues to grow, setting new records for bond issuance volume in 2007, 2014, and 2017. According to a report by Artemis, at the end of 2017, the amount of total risk capital of CAT bonds and insurance-linked securities (ILS) was US$31.036 billion.

Some meteorological studies (e.g., Maloney and Hartmann (2000), Goldenberg et al. (2001),Landsea(2005), Sutton and Hodson(2005)) attribute increases in Atlantic hurricane activities to changes in six climate indices, including the Atlantic meridional mode (AMM), Atlantic multidecadal oscillation (AMO), El Nin˜o-Southern Oscillation (ENSO), North Atlantic Oscillation (NAO), Tropical North Atlantic (TNA), and Caribbean SST index (CAR). There is also a perspective that increased carbon dioxide (CO_2) levels correlate to the high frequency of the most intense hurricane events (e.g., Henderson-Sellers et al.(1998), Knutson and Tuleya (2004)). Hence, some previousstudies (e.g., Elsner et al. (2000, 2006, 2008), Solow and Moore (2000), McDonnell and Holbrook (2004),Daneshvaran and Haji (2013)) use these climate indices as factors to forecast hurricane frequency. The literature has widely accepted that these six climate and CO_2 indices are related to the frequency of natural CATs, but it is unclear how CAT bond markets assessand price climate risks implied in these climate cycles and CO_2indices. Previous studies such as Lane (2000), Lee and Yu (2002), Lane and Mahul (2008), Galeotti et al. (2013), Braun (2016), and Gürtler et al. (2016) show that CAT bond spreads could be affected by both CAT bond-specific variables and macroeconomic factors. Instead of analyzing the impacts of CAT bond-specific factors or macroeconomic factors on CATbond spreads, this paper examines the relationship between climate information and CAT bond spreads, using primaryand secondary market data over Q2:2002 to Q1:2016.For the climate cycle measures,these six climate indices (AMM, AMO, ENSO, NAO, TNA, CAR) have some degree of dependency (Vimont and Kossin (2007), Daneshvaran andHaji (2013)). In order to avoid multicollinearity, weuse principal component analysis(PCA) to propose a climate cycleproxy combining the set of six climate indices.

Studying the primary and secondary markets of CAT bondsis also well suited for testingthe relationship between price quality and the number of traders with private information (informed traders) in the markets. Prices reflect private information via informationaggregationmechanism in financial markets (e.g., Duffieand Manso (2007); Banerjee (2011);Chenet al. (2014); Goldstein and Yang(2017)). Bossaerts et al. (2013) show that the number of informed traders increases the informativeness of the price system (price quality).Mauer and Senbet (1992) note that various types of access restriction make the primary market accessible only to a subset of the universe of investors, but the secondary market is accessible to all market participants. Thus, the secondary market of CAT bonds hasa greater number of traderswith private information(informed traders) regarding future CAT event risk than the primary market. We find that the significant determinants for CAT bond spreads in the primary market are still effective in the secondary market. This paper uses the residuals of CAT bond pricing regression as the residual risk (Xrisk) to capture unexplained risk features in the primary market. Our results also show that the residual risk (Xrisk) of each CAT bond in the primary market significantly increases its spreads in the secondary market, thus exposing a significant link

between primary and secondary markets. All component factors, including significant determinants and the residual risk, for primary market CAT bond spreads, can be incorporated into the secondary market bond spreads, which implies the secondary market for CAT bonds contains almost all information in the primary market. Furthermore, CAT bond spreads in the secondary market reveal information about future CAT risk contained in the climate cycle and CO_2 variation, but not CAT bond spreads in the primary market. Hence, we conclude that the price quality of CAT bonds in the secondary market is higher than the price quality in the primary market. Our conclusions are still valid under a series of robustness checks with different time periods, peril types, and alternative proxies for climate indices.

II. EMPIRICAL METHODOLOGY

This section discusses details on the regression analysis conducted in the next section and providesthe definitions of variables. For dependent variables, we use CAT bond spreads ofthe primary and the secondary markets at the end of each quarter. For each market, we run separate regressions using quarterly observations. Let Spread_{it}^{P} (Spread_{it}^{S}) denote the spread of CAT bond i at time tmeasured in the primary (secondary) market. We apply the regression model (A) in the primary market and model (B) in the secondary market.

$$\begin{aligned}\ln\left(\text{Spread}_{it}^{P}\right) = {} & \beta_0 + \beta_1 \text{EL}_i + \beta_2 \text{Size}_i + \beta_3 \text{Term}_i \\ & + \beta_4 \text{Trig}_i + \beta_5 \text{SR}_i + \beta_6 \text{IG}_i \\ & + \beta_7 \text{Nperils}_i + \beta_8 \text{Wind}_i + \beta_9 \text{EQ}_i \\ & + \beta_{10} \text{MT}_i + \beta_{11} \text{US}_i + \beta_{12} \text{EU}_i \\ & + \beta_{13} \text{JP}_i + \beta_{14} \text{US}_i * \text{Wind}_i \\ & + \beta_{15} \text{US}_i * \text{EQ}_i + \beta_{16} \text{EU}_i * \text{Wind}_i \\ & + \beta_{17} \text{JP}_i * \text{EQ}_i + \beta_{18} \text{RI}_t \\ & + \beta_{19} \text{BBspread}_t + \beta_{20} \text{SP500}_t \\ & + \beta_{21} \triangle \text{CO2}_t + \beta_{22} \text{Climate}_t \\ & + \varepsilon_{it} \qquad \text{(A)}\end{aligned}$$

$$\begin{aligned}\ln(\text{Spread}_{it}^{S}) = {} & \beta_0 + \beta_1 \text{EL}_i + \beta_2 \text{Size}_i + \beta_3 \text{Age}_{it} \\ & + \beta_4 \text{Term}_i + \beta_5 \text{Trig}_i + \beta_6 \text{SR}_i \\ & + \beta_7 \text{IG}_i + \beta_8 \text{Nperils}_i + \beta_9 \text{Wind}_i \\ & + \beta_{10} \text{EQ}_i + \beta_{11} \text{MT}_i + \beta_{12} \text{US}_i \\ & + \beta_{13} \text{EU}_i + \beta_{14} \text{JP}_i + \beta_{15} \text{US}_i \\ & * \text{Wind}_i + \beta_{16} \text{US}_i * \text{EQ}_i + \beta_{17} \text{EU}_i \\ & * \text{Wind}_i + \beta_{18} \text{JP}_i * \text{EQ}_i + \beta_{19} \text{Xrisk}_t \\ & + \beta_{20} \text{RI}_t + \beta_{21} \text{BBspread}_t \\ & + \beta_{22} \text{SP500}_t + \beta_{23} \triangle \text{CO2}_t \\ & + \beta_{24} \text{Climate}_t + \varepsilon_{it} \qquad \text{(B)}\end{aligned}$$

Here, β_0 is the intercept term. The subscript t in regression models (A) and (B) denotes the time of issuance and quote date, respectively; and $\ln\left(\text{Spread}_{it}^{P}\right)$ and $\ln(\text{Spread}_{it}^{S})$ take logs of CAT bond spreads in order to control for heteroscedasticity.

To control for CAT-bond specific effects on bond spreads, we follow previous studies to use expected loss (EL), issue volume (Size), term (Term), trigger type (Trig), sponsor (SR), rating (IG), complexity (Nperils), peril types (Wind, EQ, MT), and peril territory (US, EU, JP) as the measures for CAT-bond specific features in our regression models.For example, many empirical studies offer evidence showing that expected loss (EL) is the single most important driver of CAT bond spreads (e.g., Lane and Mahul (2008), Dieckmann (2011), Galeotti et al. (2013)). Expected loss (EL), as experts' forecasts of future catastrophe losses, results from the risk analysis performed by specializedfirms with different natural catastrophe risk models. Gürtler et al. (2016) use term(Term) and issue volume(Size) to measure liquidity in the secondary market of CAT bonds.Investors usually require an additional risk premium for indemnity-triggered CAT bonds due to the longer post-event loss verification process and the possibility of moral hazard by the sponsor (e.g., Lee and Yu (2002), Cummins and Weiss (2009)).

In our regression models, we build a dummy variable Trig_i. If an indemnity trigger is applied on transaction i, then Trig_i equals one and zero otherwise.Braun (2016) points out that long-standing and well-respected sponsors can afford to pay lower CAT bond spreads. We use a dummy variable to differentiate sponsors; the dummy SR_i is one when a CAT bond iis issued by Swiss Re.We build a dummy variable for investment grade (IG_i), which means rating classes from BBB upward for a CAT bondi to measure the rating effect on bond spreads.Investors also require higher risk premiums for complex CAT bonds, whichmeans a single CAT bond coversmultiple peril types and/or multiple peril regions. We useNperils_i to measure the complexity of CAT bonds, and its value ranges from one to eight.In model (B), we further consider variables Age and Xrisk, where Age is the time between the issue date and the quote date in months, and Xrisk is the residual risk that measures unexplained risk features of CAT bonds in the primary market.

For the measures of peril typesand peril territory, the dummy variableWind_iassumes a value of one, if a hurricane is referenced inCAT bond i, and EQ_i equals one for earthquake bondi.If both variables Wind_i and EQ_i are one, then transactioni is a multiperil bond (MT).The binary covariates for the covered territory are differentiated into multi-territory (MT_i), United States (US_i), Europe (EU_i), and Japan (JP_i). If none of these variables equals one, then bond ionly relates to another geographic area. We furtherconsider interaction effects for the most common combinations of territory and peril, i.e., U.S. Wind, U.S. Earthquake, Europe Wind, and Japan Earthquake.

For macroeconomic effects on CAT bond spreads, we use three variables -the quarterly returns of the S&P 500 (SP 500), BB corporate bond spreads (BB spread), and reinsurance cycleindex (RI) - to analyze the effects of capital marketdevelopments and the reinsurance cycle on CAT bond spreads. Braun (2016)

shows thatcontagion effects of spreads exist between CAT bonds and corporate bonds with thesame rating becausefixed-income investors perceive securities with thesame rating to carry identical risks.Gürtler et al. (2016) present that CAT bond spreads are significantly correlated with the reinsurance market cycle and the return of S&P 500 index.

A rise in extreme weather conditions associated with climate change usually increases the frequency and severity of some natural CATs, and it may also have an immediate impact on the CAT bond markets. In our regression models,we use the climate cycle proxy (Climate) and the quarterly change rate of CO_2 ($\triangle$ CO2) as measures for theclimate effects to examine their impacts on CAT bond spreads.

III. EMPIRICAL RESULTS

3.1 Impacts of climate information on CAT bond spreads in the primary market

To get a first-hand impression of the importance of climate and CO_2indices, in Table 1we regresstheCAT bond spreads in the primary market on our climate cycle proxy (PC123) and ΔCO_2 while controlling for other factors for CAT bond pricing according to Model (A). Consistent with previous studies, the results for Model 1 of Table 1 show that the coefficient for the expected loss (EL) is highly significant.This means that the expected loss is an important driver for CAT bond spreads in the primary market. The coefficient of the variable Termis significantly negative in Model 1, and thus CAT bond spreads in the primary market decrease with the term of the security. We further find that investment grade (IG) CAT bonds have lower bond spreads than high yield ratings.

Table 1: Impacts of Climate Change on CAT Bond Spreads in the Primary Market

	Coef.	Std. Err.	P>|t|
EL	0.0016	0.0001	0.0000
Size	-0.0003	0.0003	0.3680
Term	-0.0057	0.0016	0.0010
Trig	-0.0518	0.0505	0.3090
SR	0.0162	0.0470	0.7310
IG	-0.8044	0.1086	0.0000
Nperils	-0.0441	0.0415	0.2910
Wind	0.1967	0.0747	0.0100
EQ	0.1005	0.0923	0.2790
MT	-0.0175	0.0679	0.7970
US	0.1423	0.0941	0.1350
EU	0.0557	0.0785	0.4800
JP	-0.2051	0.1049	0.0540
US*Wind	0.3056	0.0867	0.0010
US*EQ	0.0096	0.1143	0.9330
EU*Wind	-0.0654	0.0763	0.3940
JP*EQ	0.2743	0.1316	0.0400
RI	0.0001	0.0000	0.0000
BBspread	0.0006	0.0001	0.0000
SP500	0.0000	0.0000	0.7010
△CO2	-0.0001	0.0006	0.8910
PC123	0.0224	0.0308	0.4700
_cons	5.7290	0.1359	0.0000
N		471	
R^2		0.793	

The results of Model 1 also denote that the coefficients for three CAT bond specific variables, including issued amount (Size), sponsors (SR), and number of perils (Nperils), are insignificant.Thisimplies thatissued amount, well-respected sponsors (Swiss Re), and the complexity level of a CAT bond contract do not have a significant influence on CAT bond spreads in the primary market.CAT bonds with an indemnity trigger (Trig) do not have significantly higher yield spreads than non-indemnity trigger bonds, meaningthat investors do not demand additional premium components due to the possibility of moral hazard arising from an indemnity triggermechanism (e.g., Lee and Yu (2002)). Oneplausible explanation for this phenomenon is that applyinga non-indemnity triggercan reduce or eliminate the moral hazard of an indemnity trigger mechanism, but a non-indemnity trigger also introduces basis risk for the sponsor (e.g., Cummins et al. (2004);Lee and Yu (2007)).

In terms of peril types and peril regions covered by CAT bond contracts, CAT bonds that insure hurricane events (Wind) have significantly higher spreads, and insured perils in Japan (JP) have lower spreads than CAT bonds securitizing events in other parts of the world. Concerning the interaction effects between peril types and peril regions, Model 1's results indicate that CAT bonds insuring hurricane events (Wind) in the U.S. and earthquake events (EQ) in Japan command higher spreads.

In addition to CAT bond specific variables, Model 1 also considers three macroeconomic variables that measure the impact of capital markets and the reinsurance cycle on CAT bond spreads. For capital market variables, the quarterly return of the S&P 500 Index (SP500) has no significant effect on CAT bond spreads in the primary market. Thus, newly issued CAT bonds can be regarded as "zero-beta" securities in the primary market. Our results show a positive relationship between BB corporate bond spreads (BBspread) and CAT bond spreads, meaningthat investors treat the same rated CAT and corporate bonds as carrying identical risk, and thus there is a contagion effect between CAT and corporate bond markets. For the reinsurance underwriting cycle, we find that the coefficient of the annual relative change

inthe reinsurance index (RI) is significantly positive. Therefore, CAT bond spreads fluctuate in line with the reinsurance market cycle.Recent studiesfind thatfluctuations of six climate (AMM, AMO, ENSO, NAO, TNA, and CAR) and carbon dioxide (CO_2)indices contain valid information that reflects future CAT activitiesand thus can be regarded as proxies on future CAT risk. However, the results for Model 1 show that our climate cycle proxy (PC123), which explains 89.1% of the joint variability in the six climate indices, and ΔCO_2 are both not significant drivers for CAT bond spreads. It means that the information about future CAT risk contained in thesix climate and CO_2 indices cannot be revealed by CAT bond spreads, and thus the quality of CAT bond prices is low in the primary market.

3.2 Impacts of climate information and residual risk on CAT bond spreads in the secondary market

We investigate whether the primary market's residual risk (Xrisk) of a CAT bond can influence its secondary market prices. Becausea large proportion of the variation in bond yield spreads is attributed to time-invariant variables of CAT bond-specific factors, we use the random effects (RE) models based on Model (B) to show the influence of these factors on secondary CAT bond spreads in Table 2.

Table 2: Impacts of Residual Risk, Bond-specific, and Macroeconomic Factors on CAT Bond Spreads in the Secondary Market

	Coef.	Std. Err.	P>|z|
EL	0.0019	0.0001	0.0000
Size	-0.0003	0.0001	0.0650
Age	-0.0052	0.0014	0.0000
Term	0.0000	0.0016	0.9910
Trig	0.0101	0.0432	0.8160
SR	-0.0090	0.0403	0.8240
IG	-0.6063	0.0822	0.0000
Nperils	-0.0059	0.0327	0.8560
Wind	0.1331	0.0786	0.0900
EQ	0.0793	0.0666	0.2340
MT	0.0681	0.0581	0.2410
US	0.1940	0.0562	0.0010
EU	-0.0328	0.0828	0.6920
JP	-0.3433	0.0938	0.0000
US*Wind	0.1356	0.0833	0.1040
US*EQ	-0.0722	0.0686	0.2920
EU*Wind	0.0290	0.1158	0.8030
JP*EQ	0.3526	0.1313	0.0070
Xrisk	0.0004	0.0001	0.0000
RI	0.0001	0.0000	0.0840
BBspread	0.0005	0.0000	0.0000
SP500	0.0000	0.0000	0.0120
_cons	5.3863	0.0923	0.0000
Year fixed effects		Yes	
LM statistic		5179.54	
N		4,670	
R^2		0.684	

We build the links between the primary and the secondary markets and test whether the unexplained risk feature of a CAT bond in the primary market, residual risk (Xrisk), can be interpreted as a reliable signal of its trading risks to secondary market participants. The results in Table 2 show that residual risk (Xrisk) significantly increases CAT bond spreads in the secondary market. This suggests that there are strong links between the primary market and the secondary market, and unexplained risk features of a CAT bond in the primary market are reliable trading risks to investors in the secondary market.In accordance with the findings of the primary market, both corporate bond spreads (BB spread) and reinsurance cycleindex (RI) also exert significantly positive effects on CAT bond spreads in the secondary market. The significant coefficient of the variableS&P 500 is consistent with Gürtler et al. (2016), who find a relevant correlation between capital market development and secondary CAT bond spreads.

Table 3: Impacts of Climate Change on CAT bond Spreads in the Secondary Market

	Coef.	Std. Err.	P>|z|
EL	0.0020	0.0001	0.0000
Size	-0.0002	0.0001	0.1270
Age	-0.0042	0.0014	0.0020
Term	0.0000	0.0016	0.9760
Trig	0.0294	0.0435	0.4990
SR	-0.0326	0.0398	0.4130
IG	-0.6266	0.0815	0.0000
Nperils	-0.0083	0.0329	0.8020
Wind	0.1221	0.0782	0.1190
EQ	0.0829	0.0673	0.2180
MT	0.0881	0.0589	0.1350
US	0.1842	0.0565	0.0010
EU	-0.0162	0.0831	0.8450
JP	-0.3430	0.0948	0.0000
US*Wind	0.1514	0.0831	0.0680
US*EQ	-0.0787	0.0698	0.2590
EU*Wind	0.0080	0.1158	0.9450
JP*EQ	0.3389	0.1317	0.0100
Xrisk	0.0004	0.0001	0.0000
RI	0.0001	0.0000	0.0200

BBspread	0.0004	0.0001	0.0000
SP500	-0.0001	0.0000	0.0010
▵CO2	0.0004	0.0001	0.0000
PC123	-0.0958	0.0112	0.0000
_cons	5.4135	0.0909	0.0000
Year fixed effects		Yes	
LM statistic		5336.19	
N		4,670	
R^2		0.689	

The above results of Table 1confirm that the low quality of CAT bond prices in the primary market does not reveal information about future CAT risk contained in the six climate and CO2 indices. Compared with the primary market, the secondary market is easily accessible and has more informed agents with private information. We hence test whetherCAT bond prices in the secondary market can reveal information of future CAT risk contained within the six climate and CO_2indices. Controlling other determinants for CAT bond spreads, we add our climate cycle proxy (PC123) and ΔCO_2 to employregression analysis. Table 3 shows that our climate cycle proxy (PC123) has a negative and significant correlation with secondary CAT bond spreads. The following two reasons explain the negative coefficients of PC123. 1) Our climate cycle proxy (PC123)explains 89.1% of the variation inthe six climate indices, but not all six are positivelycorrelated with CATactivities (Daneshvaran and Haji (2013)).2) Although some indices have an opposite correlation with future catastrophe activity, they also have some degree of dependency (Vimont and Kossin (2007)). For example, the annual Atlantic Basin hurricane observations are positively correlated with Tropical North Atlantic (TNA) and have a negative correlation with El Nin˜o-Southern Oscillation (ENSO). However, about 25%of the variation in TNA can be explained by ENSO fluctuations (Hameed et al. (1993), Enfield and Mayer (1997)).

Table 3 report that ΔCO2 has a positive and significant effect on CAT bond spreads in the secondary market. These results are consistent with the findings that there is a positive relationship between ΔCO_2 and the most intense hurricane events (e.g., Knuton and Tuleya (2004)), and that increased ΔCO_2 means high future catastrophe risk. Moreover, Table 3 also shows thatresidual risk (Xrisk) still has a significant and positive effect on CAT bond spreads in the secondary market,which is consistent with the results of Table 2.In contrast to CAT bond-specific factors, our climate cycle proxy (PC123), ΔCO_2, and other macroeconomic factors are not bond specific and vary by time. We apply fixed effects (FE) models to analyze whether our climate cycle proxy and ΔCO_2 can influence the CAT bond spreads in the secondary market.

CONCLUSIONS

Based on a broad dataset of CAT bonds from Q2:2002 to Q1:2016, this paper tests how climate cycle and CO_2 information affect CATbond prices and compares theirprice qualityin the primary and secondary markets. Recent studies suggest that fluctuations in six climate (AMM, AMO, ENSO, NAO, TNA, and CAR) and CO_2indices can be applied to forecastfuture CAT event risk.Using principal component analysis (PCA), we propose a new climate cycle proxy (PC123) that explains 89.1% of the joint variability in the six climate indices.However, our empirical results show that CAT bond spreads in the primary market do not revealinformation about future CAT risk contained in our climate cycle proxy (PC123) and CO_2index.

We thus build an econometric pricing model with significant determinants of CAT bond spreads to obtain the residual risk (Xrisk) of CAT bonds, capturing the primary market's unexplained risk factors.Our results show that the secondary market prices contain both priced and unpriced information in the primary market, suggesting a strong link between the primary market and the secondary market of CAT bonds.In addition to the residual risk (Xrisk) from the primary market, it is important to note thatinformation from the six climate(PC123) and CO_2indicesabout future CAT riskisfound to be statistically significant for being impounded into CAT bond spreads in the secondary market. Therefore, we conclude thatthe secondary marketfor CAT bonds has higherprice quality than the primary market since the latter cannot reveal climate cycle and CO_2 information.

REFERENCES

[1] Banerjee, S. "Learning from prices and the dispersion in beliefs." Review of Financial Studies, 24.9(2011), 3025-3068.

[2] Benfield, A. O. N."Weather, Climate & Catastrophe Insight: 2017 Annual Report." Research Report, (2017).

[3] Boehme, R., and G.Çolak."Primary market characteristics and secondary market frictions of stocks."Journal of Financial Markets, 15.2 (2012), 286-327.

[4] Bossaerts, P., C.Frydman, and J.Ledyard. "The speed of information revelation and eventual price quality in markets with insiders: comparing two theories." Review of Finance, 18.1 (2013), 1-22.

[5] Braun, A. "Pricing in the Primary Market for Cat Bonds: New Empirical Evidence." Journal of Risk and Insurance, 83.4(2016), 811-847.

[6] Chen, H., P.De, Y. J.Hu, and B. H.Hwang.Wisdom of crowds: "The value of stock opinions transmitted through social media." Review of Financial Studies, 27.5 (2014), 1367-1403.

[7] Cummins, J., D. Lalonde, and R. Phillips."The Basis Risk of Catastrophic-LossIndex Securities."Journal of Financial Economics, 71.1 (2004), 77-111.

[8] Cummins, J., and M. Weiss."Convergence of Insurance and Financial Markets:Hybrid and Securitized Risk-Transfer Solutions."Journal of Risk and Insurance, 76.3 (2009),

493-545.
[9] Daneshvaran, S. and M. Haji.“Atlantic hurricane forecast: a statistical analysis.”Journal of Risk Finance, 14(2013), 4-19.
[10] Dieckmann, S.“AConsumption-Based Evaluation of the Cat Bond Market.”WorkingPaper, University of Pennsylvania, (2011).
[11] Duffie, D., and G. Manso.“Information percolation in large markets.” American Economic Review, 97.2 (2007), 203-209.
[12] Elsner, J. B., T. Jagger, and X. Niu.“Shifts in the Rates of Major Hurricane Activity over the North Atlantic During the 20thCentury.”Geophysical Research Letters, 27 (2000), 1743-1746.
[13] Elsner, J. B., and T. H. Jagger.“Prediction Models for Annual U.S. Hurricane Counts.”American Meteorological Society, 15(2006), 2935-2952.
[14] Elsner, J. B., T. H. Jagger, M. Dickinson, and D. Rowe.“Improving MultiseasonForecasts of North Atlantic Hurricane Activity.”American Meteorological Society,15 (2008), 1209-1219.
[15] Enfield, D. B., and D. A.Mayer.“Tropical Atlantic sea surface temperature variability and its relation to El Niño-Southern Oscillation.”Journal of Geophysical Research: Oceans, 102(C1) (1997), 929-945.
[16] Henderson-Sellers, A., H. Zhang, G. Berz, K. Emanuel, W. Gray, C. Landsea, G. Holland, J. Lighthill, S.-L. Shieh, P. Webster, and K. McGuffie.“Tropical cyclones and global climate change: A post-IPCC assessment.”Bulletin of the American Meteorological Society, 79 (1998), 19-38.
[17] Galeotti, M., M.Gürtler, and C.Winkelvos.“Accuracy of Premium Calculation Modelsfor CAT Bonds - an Empirical Analysis.”Journal of Risk and Insurance, 80(2013), 401-421.
[18] Goldenberg, S. B., C. W. Landsea, A. M. Mestas-Nunez and W. M. Gray.“The recent increase in Atlantic hurricane activity: causes and implication.”Science, 293(2001), 474-479.
[19] Goldstein, I., and L.Yang.“Information disclosure in financial markets.”Annual Review of Financial Economics, 9(2017), 101-125.
[20] Gray, W. M. “Atlantic Seasonal Hurricane Activity. Part I: El Nin˜o and 30-mb Quasi-Biennial Oscillation Influences.”Monthly Weather Review, 112 (1984), 1649-1668.
[21] Gürtler, M., M.Hibbeln, and C.Winkelvos.“The impact of the financial crisis and natural catastrophes on CAT bonds.”Journal of Risk and Insurance, 83.3 (2016), 579-612.
[22] Hameed, S., A.Meinster, and K. R.Sperber.“Teleconnections of the Southern Oscillation in the tropical Atlantic sector in the OSU coupled upper ocean-atmosphere GCM.”Journal of Climate, 6.3 (1993), 487-498.
[23] Knutson T. R. and R. E. Tuleya.“Impact of CO2-induced warming on simulated hurricane intensity and precipitation: sensitivity to the choice of climate model and convective parameterization.”Journal of Climate, 17(2004), 3477-3495.
[24] Landsea, C. W.“Hurricanes and global warming.”Nature, 438(2005), E11-E13.
[25] Lane, M. N. “Pricing risk transfer transactions.” ASTIN Bulletin, 30.2 (2000), 259–293.
[26] Lane, M. N., and R. C.Beckwith. “Annual ILS Reviews.” Lane Financial L.L.C. Available at LaneFinancialLLC.com. (2003–2016).
[27] Lee, J.P., and M.T. Yu.“Pricing Default-Risky CAT Bonds with Moral Hazard and Basis Risk.”Journal of Risk and Insurance, 69 (2002),25-44.
[28] Lee, J. P., and M. T. Yu.“Valuation of catastrophe reinsurance with catastrophe bonds.”Insurance: Mathematics and Economics, 41.2 (2007), 264-278.
[29] Maloney, E. D., and D. L. Hartmann.“Modulation of hurricane activity inthe Gulf of Mexico by the Madden-Julian oscillation.”Science, 287 (2000), 2002-4.
[30] Mauer, D. C., and L. W.Senbet. “The effect of the secondary market on the pricing of initial public offerings: Theory and evidence.” Journal of Financial and Quantitative Analysis, 27.1 (1992), 55-79.
[31] McDonnell, K. A., and N. J. Holbrook.“A Poisson Regression Model of Tropical Cyclogenesis for the Australian-Southwest Pacific Ocean Region.”Weather Forecasting, 19 (2004), 440-455.
[32] Solow, A. R., and L. J. Moore.“Testing for Trend in North Atlantic Hurricane Activity, 1900-98.”Journal of Climate, 15 (2000), 3111-3114.
[33] Sutton, R. T. and D. L. R. Hodson.“Atlantic Ocean forcing of North American and European summer climate.” Science, 309 (2005), 115-118.
[34] Vimont, D. J. and J. P. Kossin.“The Atlantic meridional mode and hurricane activity.”Geophysical Research Letters, 34(2007), p. L07709.

★★★