6-2019

Marginal cost of risk-based capital and risk-taking

Tao CHEN

Jing Rong GOH
Singapore Management University, jrgoh@smu.edu.sg

Shinichi KAMIYA

Pingyi LOU

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Tao Chen
Nanyang Business School
Nanyang Technological University
E-mail: JTCHEN@ntu.edu.sg

Jing Rong Goh
Nanyang Business School
Nanyang Technological University
E-mail: C160024@e.ntu.edu.sg

Shinichi Kamiya
Nanyang Business School
Nanyang Technological University
E-mail: skamiya@ntu.edu.sg

Pingyi Lou*
School of Economics
Fudan University
E-mail: PLOU002@hotmail.com

Abstract

We explore the impact of capital adequacy requirements on financial institutions' risk-taking behavior from a novel perspective. Specifically, we show that an important feature of the risk-based capital (RBC) system—a built-in diversification benefit in aggregating risk categories— induces moral hazard. We find that insurers that face lower marginal RBC costs of fixed-income (FI) investment tend to purchase riskier FI securities. This relationship holds even when lower marginal RBC costs result from increased risk in other risk categories, which is an unintended consequence of the RBC's square root rule. Using Hurricanes Katrina and Sandy as exogenous shocks to the RBC cost, we find that insurers that suffered more in the two disasters undertook more risk in their FI investments and witnessed an increase in their overall risk. We further show that insurers with a high RBC cost sell similar risky bonds during the financial crisis, presenting a source of systemic risk. These results provide an important regulatory implication for minimum capital calculation in capital regulation regimes.

Keywords: Risk-based capital; Risk taking; Capital regulation; Insurance companies

JEL Classification: G18, G22, G32

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* Pingyi Lou, Department of Insurance, School of Economics, Fudan University. 600 Guoquan Road, Shanghai, 200433. Email: PLOU002@hotmail.com
We are grateful for the helpful comments from Alexander Carol (the editor), two anonymous referees, Chuan Yang Hwang, Jun-Koo Kang, Xiaoxuan Li, Norma Nielson, Shaun S. Wang, Chi-Shen Wei, Yuan Wu, Jubo Yan and the seminar participants from Nanyang Technological University, the 2017 Insurance Risk and Financial Risk Center Annual Conference and the 2017 American Risk and Insurance Association Annual Meeting. We acknowledge financial support from the Singapore Ministry of Education Academic Research Fund Tier 1. (Reference number: RG62/17 (NS)). All errors are our own.

Marginal Cost of Risk-based Capital and Risk-taking

Abstract

We explore the impact of capital adequacy requirements on financial institutions' risk-taking behavior from a novel perspective. Specifically, we show that an important feature of the risk-based capital (RBC) system—a built-in diversification benefit in aggregating risk categories—induces moral hazard. We find that insurers that face lower marginal RBC costs of fixed-income (FI) investment tend to purchase riskier FI securities. This relationship holds even when lower marginal RBC costs result from increased risk in other risk categories, which is an unintended consequence of the RBC's square root rule. Using Hurricanes Katrina and Sandy as exogenous shocks to the RBC cost, we find that insurers that suffered more in the two disasters undertook more risk in their FI investments and witnessed an increase in their overall risk. We further show that insurers with a high RBC cost sell similar risky bonds during the financial crisis, presenting a source of systemic risk. These results provide an important regulatory implication for minimum capital calculation in capital regulation regimes.

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1. Introduction

Capital regulations dissuade financial institutions from excessive risk-taking and prevent their insolvency by ensuring that these institutions hold adequate capital. However, their effectiveness in dissuading risk-taking behavior is debatable (VanHoose, 2007). Opponents have argued that capital requirements distort company behavior and can increase risk-taking (e.g., Becker and Ivashina, 2015; Calem and Rob, 1999; Kim and Santomero, 1988; Koehn and Santomero, 1980). Most prior studies focus on the impact of the overall level of regulatory capital on financial institutions' risk-taking behavior, but little attention has been paid to the impact caused by the composition of the regulatory capital. We show that specific interactions between the risk components assumed in regulatory capital calculations may encourage risk-taking.

The regulatory frameworks require financial institutions to hold a minimum required firm-level capital by aggregating all possible risks from their assets and liabilities, to protect the institutions from simultaneous losses in a stressed situation. Therefore, through the aggregation process, the composition of regulatory capital can play a key role in the design of capital regulations.

To illustrate how the aggregation approach and the composition of regulatory capital will affect the risk-taking behavior of financial institutions, we utilize the structure of the risk-based capital (RBC) calculation employed by the U.S. insurance companies. Under the current U.S. RBC system, there are six risk categories for property and casualty (P&C) insurance companies and each category has its associated capital charges. The RBC system requires insurers to aggregate risks through the square root rule (i.e., the square root of the sum of the squared-risk charges), under an assumption of independence between risk categories. However, as we will show later, the independence assumption implied by the square root rule leads to the inevitable dependence of the regulatory cost of risk-taking in one risk category on other risk categories.

Smith (1998) documents the anecdotal evidence of this interdependence within the U.S. life insurance industry, an industry that has similar capital regulations as that of the P&C insurance companies. In 1995, GE Capital acquired Amex Life Insurance at a price having "a huge competitive advantage" (Smith, 1998). Based on information provided by the company's sources, Smith (1998) explained that this was attributed to the investment-risk orientation of GE Capital and the orientation of Amex life to underwriting risk. This predetermined zero correlation between the two risk categories led to a limited incremental required capital for GE. Consequently, this potential saving of regulatory capital enabled GE to bid a higher price as it allowed the company to undertake greater underwriting risk at a relatively lower regulatory cost compared to its peers.

Inspired by this example, we derive the conditions of optimal risk-taking and hypothesize that insurers' investment decisions might be unexpectedly distorted by the marginal regulatory cost of investment. If insurers' investment risk contributes a lower proportion to the total risk charge, the capital cost for an additional dollar (i.e., marginal cost) decreases in this risk category.[1] Subsequently, insurers may take advantage of the opportunity to seek a higher profit at a lower capital cost. This illustrates a specific channel through which the built-in diversification benefits of the RBC system may have unintended consequences on the risk-taking behavior of insurance companies.

In our empirical analyses, we examine how the RBC formula affects P&C insurers' risk-taking behavior in fixed-income (FI) security holdings, the largest portion of total investments by P&C

[1] The effect of marginal RBC cost has been pointed out in practitioners' reports. Feldblum (1996) discusses the effect on reserve management incentive, mainly focusing on the liability side of the balance sheet. Zeppetalla (2002) conducts a marginal analysis of RBC and suggests that insurers optimally allocate risks to produce the minimum regulatory capital. We provide the first empirical evidence that insurers adjust their portfolio's risky investments in response to the RBC formula.

insurers.[2] Using a sample of U.S. P&C insurance companies from 2003 to 2010, we find that insurers with a lower marginal RBC cost of FI investments at the beginning of the year increase the amount of the risk taken in their portfolio of FI investments for that year. Particularly, we show that these companies buy more and sell less *non-investment grade* or *downgraded* bonds. Our argument is also supported by equity holdings, the second-largest portion of the total invested assets by P&C insurers.

To mitigate the endogeneity concern, we examine the impact of an exogenous shock on the marginal RBC cost of FI security holdings. We examine how insurers adjusted their investment behavior after being impacted by Hurricanes Katrina and Sandy.[3] Both hurricanes led affected insurers to accumulate huge loss reserves for their claimants and raise their capital requirement for the reserve risk. This implies that, for a given amount of risk in the FI investment, an increase in the capital charge of the reserve risk translates to a decrease in RBC costs of acquiring additional units of risky FI securities. We show that insurers reporting higher coverage relevant to hurricane loss in severely affected states undertook more risk in their bond investments and purchased riskier bonds after those hurricanes. Our result is robust to controlling for shocks on capital adequacy.

We reveal that insurers fail to control their overall risk wherein an increase in risky bond investment increases the firm's volatility of return on assets (ROA) and overall insolvency probability, as measured by the z-score. Our analysis of these natural disasters highlights the

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[2] At the end of 2015, 68% and 12% of P&C insurers' total invested assets were in FI securities and common stocks, respectively, representing the two largest investment categories by P&C insurers. Some FI instruments can be risky. A substantial risk may be posed to insurers by the high volatility in the high-yield bond market, mortgage-backed securities (MBS) market, asset-backed securities (ABS) market, and FI derivative product market. Thus, by investigating investment decisions in the most important asset class having a considerable variation in risk, we document the importance of insurers' distorted risk-taking incentives using the RBC formula.

[3] Hurricanes Katrina and Sandy were the costliest natural disasters, measured by consumer price index (CPI) adjusted losses, in the U.S. history by the time we finished the main draft. See section 6 for the description of these two hurricanes.

unintended consequence of the predetermined interactions between the risk categories incorporated within the square root rule of the RBC calculation.

Furthermore, we provide evidence that the marginal RBC costs, arising from the square root rule, provides implications for the broader financial market. On the one hand, when insurers face a higher marginal RBC FI cost, they are more likely to sell risky FI securities. This behavior is a potential source of systemic risk because we find that insurers facing a higher marginal RBC FI cost in times of financial crises tend to sell similar risky FI securities. The results continue to hold even if the high-level of marginal RBC FI cost is caused by risk charges of the stock investment and underwriting business. This implies a spillover effect from the stock and insurance markets to the fixed-income security market. On the other hand, although our results are based on a setting comprising insurance companies, we argue that our results also hold significance for the banks and other participants of the financial system. This is because the covariance adjustments in the capital regulatory regime between these different entities are not significantly different and have much in common[4].

This study contributes to the extensive literature on how minimum capital standards may affect financial institutions' risk-taking behavior (e.g., Calem and Rob, 1999; Furlong and Keeley, 1989; Gennotte and Pyle, 1991; Kahane, 1977; Kareken and Wallace, 1978; Keeley and Furlong, 1990; Kim and Santomero, 1988; Koehn and Santomero, 1980). The literature has mainly focused on how the capital adequacy level is related to risky investments by insurers, and mixed results have

[4] In the insurance industry, the covariance adjustment is found in Solvency II in the European Union (e.g., Cofield et al., 2012) and the minimum continuing capital and surplus requirement (MCCSR) system in Canada. Other insurance regulatory regimes using it include, but are not limited to, Japan, Singapore, and Australia. In the banking industry, similar adjustments have been adopted in risk categories in both Basel II and Basel III. Covariance adjustment is applied in both their standard and internal model approaches to set minimum capital requirements for market risks (BIS, 2016). We thank the referee for pointing it out.

been documented.[5] Our findings suggest that risk-taking behavior is not only affected by the level of required capital but is also affected by the composition of the required capital. This risk charge composition and the aggregation approach jointly determines the marginal regulatory cost of risk-taking in each risk category. Using the RBC regime in the U.S. P&C insurance industry as the research setting, we show that insurers actively make decisions on risky investments in response to the associated marginal RBC costs.

We also contribute to the literature on the regulatory design of the minimum capital requirement. In investigating the impact of the RBC requirement, the literature has focused mainly on risk weights. For example, Becker and Opp (2013) and Hanley and Nikolova (2015) find that a decrease in the risk weights assigned to mortgaged-backed securities increases insurers' risky investment in that asset category. Behn et al. (2016) show that banks reduce loans that are under the model-based regulation because the corresponding risk weights increase during a financial crisis. Acharya et al. (2014) find that regulatory risk weights in banking stress tests fail to represent the economic risk. Other studies reveal that in addition to risk weights, the imperfect benchmarks regime (Becker and Ivashina, 2015) and regulatory accounting rules (Ellul et al., 2015) are related to greater risk-taking. However, we emphasize the importance of the risk aggregation approach. Specifically, we focus on the regulatory cost implicitly assigned by the calculation rule, which assumes a particular interaction between risk categories. Cathcart et al. (2015) find a similar motivation and focus on the importance of the RBC formula in linking the capital and leverage ratios, especially during a credit crisis.[6]

[5] For example, Furlong and Keeley (1989) and Keeley and Furlong (1990) show that risk-taking decreases with an increase in capital, whereas Gennotte and Pyle (1991), Kim and Santomero (1988), and Koehn and Santomero (1980) show that the converse is true.
[6] However, they do not explicitly explore how the formula may affect risk-taking by banks.

The remainder of the paper is as follows. Section 2 sketches the institutional background. Section 3 presents the model. Sections 4, 5, and 6 outline the research design and present the empirical findings. Section 7 discusses the implications for systemic risks. Sections 8 and 9 provide robustness checks and concluding remarks.

2. Institutional background

2.1. The risk-based capital system and its components

In the U.S. insurance industry, the RBC system was adopted for life and P&C insurers in 1993 and 1994, respectively. It has since been regarded as the main capital adequacy monitoring tool by the National Association of Insurance Commissioners (NAIC), the regulatory authority of the insurance industry. According to the NAIC, "RBC limits the amount of risk a company can take. It requires a company with a higher amount of risk to hold a higher amount of capital."[7] In the RBC system, capital adequacy is assessed by the RBC ratio, defined as the ratio of total adjusted capital (TAC) to the firm's overall RBC as follows:

$$RBC\ ratio = \frac{Total\ adjusted\ capital(TAC)}{0.5 \times Risk-based\ capital(RBC)} \qquad (1)$$

where TAC primarily consists of capital (termed as "surplus" in the insurance industry), and RBC is the required capital that reflects business and asset risks. RBC is the aggregation of capital charges of different risk categories. Regulatory action, which is associated with significant costs, can be imposed on an insurer with a low RBC ratio.[8]

[7] http://www.naic.org/cipr_topics/topic_risk_based_capital.htm

[8] If the company meets the RBC standard, NAIC regulators take no action; if not, the lower RBC ratio this company has, the higher control level NAIC regulators will take on the company. There are four levels of regulatory action

There are six risk categories for P&C insurance companies, denoted as R_0, R_1, R_2, R_3, R_4, and R_5.[9] Risk charge R_0 denotes risk in the insurance affiliates of the insurer. Risk charge R_1 denotes a capital charge for all FI securities, such as government bonds; municipal and corporate bonds; mortgage loans; and MBS, ABS, and other structured securities. Risk charge R_2 denotes a capital charge for all equity investments, which mainly consists of common and preferred stocks. Risk charge R_3 denotes credit risk of assets that imply exposure to credit risk. It is a capital charge on reinsurance recoverable and other receivables. Risk charge R_4 denotes reserve risk, which mainly consists of a risk charge for loss and loss-adjusted expense reserve. Risk charge R_5 denotes a capital charge for premiums written in different business lines.

In risk category R_1, which measures the overall risk of insurers' FI security holdings, the risk of each security is assessed by the NAIC's security valuation office (SVO), which assigns an NAIC designation for each security in an insurer's portfolio. The Online Appendix 2 summarizes the one-to-one mapping from the credit rating provided by major rating agencies to the SVO designation. The SVO designation ranges from 1 to 6, and a higher designation implies greater risk. Specifically, securities with designations equal to or greater than 3 are regarded as risky assets and would require the insurer to hold more capital.

In the risk category R_2, all the unaffiliated common stocks are charged a flat rate of 15% of stock holdings. The treatment for unaffiliated preferred stocks is the same as that for FI securities as per the R_1 above.

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depending on an insurer's RBC ratio. The company's action level is 150% to 200%, the regulatory capital level is 100% to 150%, the authorized control level is 70% to 100%, and the mandatory control level is below 70%. NAIC's regulatory actions include rehabilitating, liquidating the insurer and placing the insurer under regulatory supervision etc.

[9] Online Appendix 1 describes the risk categories in detail.

2.2. Covariance adjustment and firm-level risk-based capital

The firm-level RBC is not a simple summation of all individual charges (i.e., $\sum_{i=0}^{5} R_i$), but it is determined by the following formula:

$$RBC = R_0 + \sqrt{{R_1}^2 + {R_2}^2 + {R_3}^2 + {R_4}^2 + {R_5}^2} \quad (2)$$

The square root rule applied from R_1 to R_5 represents the diversification effect between risk categories (termed as "covariance adjustment" in the U.S. RBC regime). The implicit assumption underlying the square root rule is that these five risk categories are independent, which is considered more reasonable than the perfect correlation assumption underlying the simple summation of risk charges.[10] Feldblum (1996) and Zeppetella (2002) illustrate that the square root rule is related to the marginal effect of each risk charge on the total capital requirement. In the case of a differentiable RBC formula, the marginal contribution of each risk category to RBC can be found by taking the first derivative of RBC with respect to the risk category. Accordingly, the marginal capital requirement for an additional dollar increase in risk category *j* can be defined as follows:

$$\frac{\partial RBC}{\partial R_j} = \frac{R_j}{\sqrt{{R_1}^2 + {R_2}^2 + {R_3}^2 + {R_4}^2 + {R_5}^2}} \text{ for } 1 \leq j \leq 5 \quad (3)$$

Equation (3) shows that an increase in the overall RBC due to an increase in the risk category *j* is given by its share in firm-level RBC excluding R_0. An important implication of equation (3) is that the marginal charge for an additional dollar increase in any risk category depends on the insurer's risk portfolio, which varies across companies and time. Conversely, if equation (2) presented a

[10] Butsic (1994) shows that the degree of correlation between risk elements is critical in setting capital levels, and a simple square root rule incorporates the correlation.

simple summation of R_0 to R_5, then the marginal charge would have been the same for all insurers, independent of other risk categories. Additionally, concerning the alternative risk category *i* (i.e., $\frac{\partial^2 RBC}{\partial R_i \partial R_j}$), we can solve the partial derivative of the marginal cost of risk category *j* from equation (3). It is negative, implying that the RBC cost of risk category *j* can be reduced when the risk charge increases in another risk category *i*. We will discuss it elaborately in section 3.

3. Model

To examine how the RBC rule shapes insurers' investment strategies, we develop a stylized model for a single-period investment optimization problem. We assume that an insurer that maintains a given RBC ratio chooses the extent of investment risk, denoted by R_1 and R_2,[11] and that the investment yields the expected value, $V(R_i)$ for i=1,2. We assume that the RBC is differentiable with respect to the choice of investment risks and that $V(R_i)$ is a concave value function (V'>0, V''<0) representing the risk-return spectrum. The insurer holds a capital, K, that incurs a cost, c, per unit capital. Hence, the capital cost is assumed to be cK. Furthermore, the target RBC ratio is defined by $F=K/$RBC.

The investment problem is defined as follows:

$$\max_{\{R_1,R_2\}} \sum_{i=1}^{2} V(R_i) - cK$$

subject to the following constraint:

[11] From Section 2, R_1 is the risk charge of FI security investment, and R_2 is the risk charge of equity investment.

$$\frac{K}{RBC} = F.$$

The objective function can be rewritten as follows:

$$\sum_{i=1}^{2} V(R_i) - cF \times RBC$$

The first-order condition with respect to the risk level of the risky FI security investment R_1 is shown as follows:

$$\frac{\partial V}{\partial R_1} = cF\left(\frac{\partial RBC}{\partial R_1}\right) \tag{4}$$

It is clear that the second-order condition is satisfied. In the first-order condition, the left-hand side is the marginal benefit of investment in risky FI securities, and the right-hand side is the marginal cost of the investment. Substituting the RBC formula into the first-order condition, we find that the optimal risk-taking on the risky FI security investment is determined by the following relationship:

$$\frac{\partial V}{\partial R_1} = cF\left(\frac{R_1}{\sqrt{{R_1}^2+{R_2}^2+{R_3}^2+{R_4}^2+{R_5}^2}}\right) \tag{5}$$

According to the prediction by the model, we hypothesize that insurance companies facing a lower contemporaneous RBC cost of FI security risk will subsequently undertake more risk in their portfolio of FI security investments (R_1), which may be achieved by increasing the holdings of the non-investment grade and downgraded FI instruments. Equation (5) also implies that when other risks increase (e.g., when the reserve risk charge R_4 increases), the marginal RBC cost of R_1 decreases, thereby increasing the optimal level of R_1. Thus, an exogenous shock on reserve risk is expected to increase the extent of risky FI security investment, providing a prediction regarding the impacts of major hurricanes on the investments reported in Section 6.

4. Data and sample

4.1. Data and variables

4.1.1. Risky fixed-income security investment

To assess the marginal RBC cost effect on risky FI security investment, we first examine the relationship between the marginal RBC cost of R_1 and the change in R_1, the risk charge for the portfolio of FI securities including government bonds, municipal and corporate bonds, mortgage loans, MBS, and ABS.

To further investigate insurers' risky bond-investment behavior, we define risky FI securities as non-investment grade or downgraded FI securities (Becker and Ivashina, 2015; Duchin and Sosyura, 2014; Ellul et al., 2015), which are identified by SVO designations from the NAIC Schedule D. Non-investment grade FI securities are instruments with designations equal to or greater than 3, which corresponds to bonds with S&P ratings lower than BB+ (Online Appendix 2). We define downgraded FI securities as instruments with SVO designations that have deteriorated when compared to the previous year.

4.1.2. Variables of interest: Risk-taking behavior by insurers

First, we measure insurers' risk-taking in the portfolio of FI securities by using the growth rate of R_1 (i.e., the risk charge for FI securities).

To better capture insurers' investment in risky FI securities, we use the data on insurers' transactions and positions of FI securities obtained from the NAIC Schedule D, which provides detailed transaction and year-end holdings at the security level (9-digit CUSIP level). Using the transaction data, we calculate the real purchases and sales of FI securities, disregarding the changes in the holdings that arise from maturity, repayment, calls, and other non-trading activities[12] (e.g., Hanley and Nikolova, 2015). Focusing on risky investments, we construct four dependent variables for non-investment grade and downgraded FI securities.

NoninvtFI Buy (*DownFI Buy*) measures the purchase of non-investment grade (downgraded) FI securities. It is defined as the book-adjusted carrying value (BACV) of the acquired non-investment grade (downgraded) FI securities on the purchase day,[13] scaled by the year-beginning BACV of the insurer's FI holdings.

NoninvtFI Sell (*DownFI Sell*) measures the sale of non-investment grade (downgraded) FI securities. It is defined as the BACV of the non-investment grade (downgraded) FI securities that are sold, scaled by the year-beginning BACV of the insurer's FI holdings.

We further construct *NoninvtFI Net Buy* (*DownFI Net Buy*) to measure insurers' net investment in non-investment grade (downgraded) FI securities. *NoninvtFI Net Buy* is calculated as the difference between *NoninvtFI Buy* and *NoninvtFI Sell.* Similarly, *DownFI Net Buy* is calculated as the difference between *DownFI Buy* and *DownFI Sell.*

[12] Column 5 of Schedule D - Part 4 reports the name of the purchaser. We define the trading as a non-trading activity if the name of the purchaser includes the following keywords: "MATURITY," "MBS PAYDOWN," "SCHEDULED REDEMPTION," "PAID ON PRINCIPAL," "CALL," "MATURED," "REDEMPTION," "MORTGAGE PRINCIPAL PAYMENT," "PRINCIPAL REDUCTION," "PRINCIPAL PAYMENT," "SINKING FUND REDEMPTION," "REDEEMED," "MBS PMT," "PAID DOWN," "PRINCIPAL REPAYMENT," "PRINCIPAL PAYDOWNS," "PRIOR YEAR INCOME," and "PRINCIPAL PAYMENT."
[13] The BACV at the purchase day is the actual cost paid by the insurer to acquire the bond.

To measure the proportion of risky FI securities in the net purchase of all FI securities during the year, we construct the variable *NoninvtFI Net Share* (*DownFI Net Share*). It is calculated as the net purchase of non-investment grade (downgraded) FI securities, which is scaled by the net purchase of all FI securities during the same year, instead of being scaled by the year-beginning holdings of all FI securities.

4.1.3. Marginal risk-based capital cost of risky fixed-income security holdings

Although the marginal RBC cost of risky FI security investment is defined in equation (3), the data on each risk charge is not readily available. Therefore, we manually calculate risk charges R_0, R_1, and R_2 using data obtained from the insurance companies' annual NAIC statements.[14] In our calculation of R_1 and R_2, we follow Feldblum (1996) and NAIC's instructions (NAIC, 2015) by considering the bond size and concentration factors. The denominator of the marginal RBC cost of FI investment is calculated by subtracting R_0 from firm-level RBC (*RBC*). Thus, we derive the marginal RBC cost of risky FI securities (*RBC Cost FI*), expressed as $R_1/(RBC\text{-}R_0)$. The marginal RBC cost of equity investment (*RBC Cost Stock*) is expressed as $R_2/(RBC\text{-}R_0)$.

4.1.4. Control variables

In the following analyses, we control for several firm characteristics that can be classified into two broad categories. The first set of control variables consists of insurers' operations and profitability (Cheng and Weiss, 2012; Ellul et al., 2011; Lin et al., 2014). This group includes the RBC ratio (as per equation (1)), leverage ratio (liability scaled by admitted assets), return on equity (ROE; net income divided by surplus), size of capital (natural logarithm of surplus), business concentration (line of business Herfindahl index), geographic concentration (geographic

[14] The NAIC's annual statements do not disclose sufficient information and data to calculate R_3, R_4, and R_5.

Herfindahl index), long-tail business (direct premiums written (DPW) in long-tail business lines divided by the total DPW), organizational form (mutual or stock insurer), and group affiliation (whether the insurer is affiliated to an insurance group).

The second set of control variables is expected to explain insurers' investment portfolio characteristics (Ellul et al., 2015; Yu et al., 2008). This group includes the proportion of non-investment grade FI securities in the total FI security holdings; the proportion of downgraded FI securities in the total FI security holdings; the share of risky assets in the total invested assets (i.e., the book value of equity investment, real asset investment, mortgage loan investment, and other long-term investment, scaled by the insurer's total invested assets); and portfolio maturity (the average maturity of the insurer's FI portfolio weighted by its book value). Both groups of control variables are measured at the beginning of the year. Appendix 1 provides detailed descriptions of all the variables.

4.2. Sample construction

Our sample comprises of all U.S. P&C insurers' annual filing reports to the NAIC from 2003 to 2010. We do not include 2011 to 2015 in our main sample due to RBC's regulatory reforms in 2009 and 2010, which took effect in 2010 and 2011, respectively (Becker and Opp 2013; Hanley and Nikolova 2015).[15]

We exclude insurers with missing or negative asset values and only include insurers with positive DPWs and net written premiums to ensure that our sampled insurers are active. Insurer-year observations with missing RBC values and insurers that report negative R_1 risk charges are

[15] However, to ensure the relevance of our results in the present-day, in the robustness tests, we expanded our sample period to run from 2003 to 2015. Furthermore, we excluded MBS FI securities to ensure that our sample is free from bias arising from regulatory reforms on MBS FI securities. We continue to report robust support for our hypothesis, as presented in detail under section 8.

excluded. Due to a lack of detailed financial information on insurers' affiliates, we exclude insurers with investments in affiliated insurance companies[16] to ensure that our calculation for risk charges R_0 to R_2 is accurate.[17] Only insurer-year observations with positive holdings of non-investment grade FI securities at the beginning of the year are included. Including insurers with no investment in risky FI securities biases the results towards our hypothesis, as these insurers have nothing to sell in the current year and have low RBC costs of risky FI securities. Our final sample includes 4,226 insurer-year observations from 2003 to 2010, with 1,122 unique insurers.[18]

4.3. Summary statistics

Table 1 presents the summary statistics for our sample. The average annual growth rate of risk charge in FI investments (R_1) is 11.1%. The average sale and purchase of non-investment grade FI securities (*NoninvtFI Sell* and *NoninvtFI Buy*) account for, approximately, 0.68% and 0.5% of all the FI security holdings at year-beginning, respectively. The average sale and purchase of downgraded FI securities (*DownFI Sell* and *DownFI Buy*) account for, approximately, 0.56% and 0.24% of all the FI security holdings, respectively. Thus, the average size of transactions of non-investment grade FI securities is larger than that of downgraded FI securities. The means of the

[16] Each insurer is required to report its investment in common stocks, preferred stocks, or bonds in its affiliates under the NAIC Schedule D, Part 6, which is divided into the following eight categories: (1) "Parent," (2)"US P&C," (3) "US life," (4) "US health," (5) "Alien insurer," (6) "Non-insurers that control insurers," (7) "Investment subsidiary," and (8) "Other affiliates." We identify insurers that have not invested in affiliated insurance companies as those reporting zero investment in common stocks, preferred stocks, or bonds under the category (2), (3), (4), (5), and (6). Furthermore, we also drop insurers reporting a positive investment in (7) "Investment subsidiary" as the risk-based capital charge for this type of investment is determined by considering its investment holdings through the subsidiary; however, we do not possess information about their investment holdings. Please refer to NAIC (2015) for detailed information.

[17] To calculate R_0, we need detailed financial statement information of all the insurance affiliates in which the reporting insurer has a positive investment. However, we do not have financial information on the affiliates operating outside of the U.S. Hence, we exclude insurers with a positive investment in the affiliates. This requirement excludes 2,389 firm-year observations (approximately 36%). This restriction excludes relatively large insurers from our sample. The summary statistics of the universe of insurers can be made available by the authors upon request.

[18] Our final sample accounts for approximately 61% of total annual industry assets and 28% of the number of the insurers in the industry.

net purchases of both risky FI securities (*NoninvtFI Net Buy* and *DownFI Net Buy*) are negative. This indicates that the average insurer reduced speculative holdings during the sample period.

Our main explanatory variable, the average marginal RBC cost of acquiring one additional dollar of risky FI securities (*RBC Cost FI*), is 0.08, and has substantial variation across insurers and time. Concerning the other firm-level control variables, the average RBC ratio is 1,218%, which is significantly higher than the Company Action Level RBC of 200%. This indicates that most of the insurers have adequate capital. Concerning the organizational structure, 62.1% of our sample insurers belong to a business group, and 17% of them are mutual insurers. Concerning the business operation variables, the average ROE is 6.8%. This indicates that the insurers were generally profitable during the sample period. The average insurer in our sample holds capital and a surplus of USD 36.7 ($=e^{10.51}/1{,}000$) million. Our business and geographic concentration measures (*Lob Herfindahl* and *Geo Herfindahl*) have mean values of 0.53 and 0.56, respectively, showing that business portfolios are diversified across different business lines and states. The average firm in our sample has 73.2% of long-tail insurance business (*Longtail*), representing a significant portion of the firms' business portfolios.

Concerning an insurer's investment portfolio's characteristics, an average insurer's holdings of speculative-(*NoninvtFI Position*) and downgraded FI securities (*DownFI Position*) are, approximately, 2.8% and 2.5% of the insurer's total FI security holdings, respectively. An average insurer holds 12.6% of the risky assets, other than the risky FI securities (*Other Risky Assets*), among its invested assets.

5. Empirical methodology and results

5.1. Risk-based capital cost of FI securities and insurers' risky investment

In this section, we first examine whether insurers facing low RBC costs of FI securities increase the risk charge in R_1. Subsequently, we focus on the trading of two specific classes of FI investments—non-investment grade- and downgraded FI securities.

We consider the following linear model with firm-fixed effects to reduce concerns about omitted variables:

$$Growth\ of\ R_1\ or\ Noninvt\ trade(Down\ trade)_{it} = \alpha_0 + \alpha_i + \alpha_t + \beta(RBC\ cost\ FI)_{it-1} + \gamma_x X_{it-1} + \varepsilon_{it} \quad (6)$$

where α_0, α_i, and α_t represent constant, firm *i* fixed effect and year *t* fixed effect, respectively. The normally distributed error term is denoted by ε_{it}. The dependent variable is either growth rate of R_1 or insurers' risky FI investment proxies. As described in Section 4.1.2, we construct four alternative variables to describe insurers' trading behavior for each non-investment grade- (*Noninvt trade*) and downgraded FI securities (*Down trade*). These four variables are *NoninvtFI Sell*, *NoninvtFI Buy*, *NoninvtFI Net Buy,* and *NoninvtFI Net Share* for non-investment grade FI securities, and *DownFI Sell*, *DownFI Buy*, *DownFI Net Buy,* and *DownFI Net Share* for downgraded FI securities.

Our explanatory variables include insurers' RBC cost of acquiring FI securities, which is also our key independent variable of interest, a *k*-vector of insurer-level control variables, and a set of firm- and year-fixed effects. We are primarily interested in the parameter β as it captures the influence of RBC cost on risky FI security investments. We also calculate robust standard errors clustered by insurance companies.

The first column of Table 2 reports the ordinary least squares regression results for the growth of risk charge R_1. The coefficient of *RBC Cost FI* is negative and significant, implying insurers that face lower RBC costs of FI securities increase the overall risk level of the FI security portfolio, R_1. If the RBC cost of FI securities drops from the third to the first quartile of the distribution of *RBC Cost FI* (i.e., by -0.051), then the risk charge in R_1 would marginally increase by 18.9%.[19] This substantial increase in the risk charge of the FI security portfolio supports our hypothesis that insurers with lower RBC cost of FI securities will increase the R_1 investment.

Columns 2 to 3 of Table 2 report the results for insurers' investments in risky FI securities, which are measured by the net purchase of non-investment grade and downgraded FI securities. The coefficients of *RBC Cost FI* are negative and significant in columns 2 and 3, indicating that insurers with lower (higher) RBC costs tend to purchase more (less) non-investment grade and downgraded FI securities. We also estimate the impact of the marginal RBC cost to better understand the economic significance of our results. If the RBC cost of FI securities drops from the third to the first quartile of the distribution of our sample *RBC Cost FI* (i.e., by -0.051), then the average firm's scaled purchase of non-investment grade FI securities would increase by 142%, and its scaled purchase of downgraded FI securities would increase by 57.6%.[20] Thus, our results are also economically significant.

Concerning other firm-level characteristics, the RBC ratio is significant and positively related to the net purchase of risky FI securities, which is consistent with the literature (Ellul et al., 2011; Ellul et al., 2015). We also find that a higher ROE is related to a higher net purchase of risky FI securities. Concerning the investment portfolio's characteristics, we observe that the proportion of

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[19] 0.189=-3.7002*(-0.051)

[20] 1.42=-0.051*(-0.0504)/|-0.0018|, wherein -0.0018 is the average of *NoninvtFI Net Buy*. 0.576=-0.051*(-0.0362)/|-0.0032|, wherein -0.0032 is the average of *DownFI Net Buy* (Table 1).

other risky assets (*Other Risky Assets*) is positively related to the net purchase of risky FI securities, which is consistent with the finding of Ellul *et al.* (2015). They argue that the proportion of risky asset measures the risk appetite of an insurer. We also show that initial holdings of risky FI positions (*NoninvtFI Position* and *DownFI Position*) are negatively related to the net purchase of risky FI securities.

In columns 4 and 5, we use *NoninvtFI Net Share* and *DownFI Net Share* as dependent variables to effectively examine the choice of risky FI securities in the total current-year investment by insurers. These dependent variables denote the net purchase of risky FI securities, scaled by the current-year net purchase of FI securities instead of the year-beginning FI holdings. We study the share of risky FI investment in the total FI net purchase to investigate the alternative hypothesis in which our initial results may be driven by a scenario wherein insurers increase their purchase of both risky and non-risky FI securities while the mix of risky and non-risky investment stays constant or even decreases.

The results in columns 4 and 5 consistently show that the alternative hypothesis does not hold true because the marginal RBC cost of FI investment is negatively associated with the share of risky FI investment. The results indicate that insurers facing lower RBC costs of risky FI securities increase their net purchase of risky FI securities more than that of non-risky FI securities. We also document the economic significance of our results. If the RBC cost of FI securities declines from the third to the first quartile of the distribution of our sample *RBC Cost FI* (i.e., by -0.051), then the share of non-investment grade FI securities in the total net purchase of FI securities would increase by 370.7% and the share of downgraded FI securities would increase by 48.7%. These results suggest that insurers with lower RBC costs of FI securities increase their net purchase of risky investment. Hence, the risk of the entire FI portfolio increases when the insurers face lower RBC costs of FI securities.

To better understand insurers' investment behavior, we disaggregate the net purchase of risky FI securities into FI-selling (*NoninvtFI Sell* or *DownFI sell*) and FI-purchasing (*NoninvtFI Buy* or *DownFI Buy*). Insurers with higher RBC costs of FI investment receive more capital relief for selling risky FI securities than insurers with lower costs. Thus, the coefficient of *RBC Cost FI* is expected to be positive in the FI-selling regressions. Furthermore, insurers with higher RBC costs of FI investment face higher capital charges for acquiring risky FI securities than insurers with lower costs. Thus, the coefficient of *RBC Cost FI* is expected to be negative in the FI-purchasing regressions.

Table 3 reports the regression results for the non-investment grade- (columns 1 to 2) and downgraded FI securities (columns 3 to 4), by disaggregating the net purchase of risky FI securities. We observe that the coefficients of the marginal RBC cost of FI securities are significant with positive signs in columns 1 and 3 and with negative signs in columns 2 and 4. These results show that insurers with lower RBC costs for acquiring risky FI securities tend to purchase more and sell less non-investment grade and downgraded FI securities. If the RBC cost of FI securities declines from the third to the first quartile of the distribution of our sample *RBC Cost FI* (i.e., by -0.051), then the average firm would decrease its selling of non-investment grade FI securities by 10.2% and that of downgraded FI securities by 13.8%. Furthermore, this decrease in the RBC cost of FI securities translates to a 37.5% increase in the purchase of non-investment grade FI securities and a 44.8% increase in the purchase of downgraded FI securities, which are economically significant.

Collectively, these results support our argument that insurer investment behavior responds to their marginal RBC cost. Insurers undertake more risk in their financial investments to seek higher profits due to the reduced cost of risk-taking.

5.2. Domestically controlled versus foreign-controlled insurers

The RBC system is applied to all insurers domiciled in the United States of America. However, an insurer's risk-taking behavior is inadvertently affected by its parent firm's regulatory regime, which may be different from that of the U.S. RBC system (e.g., Solvency II in the European Union). Therefore, being controlled by an U.S. insurer or a foreign insurer makes the difference.

To illustrate how capital requirement formulae are different, we compare the Solvency II formula for the basic solvency capital requirement (BSCR) to the U.S. RBC formula. The required capital or BSCR under Solvency II is calculated as follows:

$$BSCR = \text{Intangible asset} + \sqrt{\sum_{i \neq j} \rho_{ij} C_i C_j + \sum_{i} {C_i}^2}$$

where C_i denotes Solvency II's risky component. In Solvency II, a set of correlation parameters, ρ_{ij}, is pre-determined in the model, whereas the correlation between risk components is assumed to be 0 in the U.S. RBC formula. The marginal contribution of risk component j in Solvency II can be obtained by taking the first derivative of the BSCR with respect to C_j:

$$\frac{\partial BSCR}{\partial C_j} = \frac{2C_j + \sum_{i \neq j} \rho_{ij} C_i}{2 * \sqrt{\sum_{i \neq j} \rho_{ij} C_i C_j + \sum_{i} {C_i}^2}}$$

Thus, the marginal contribution of a risk category is consistent with that of the RBC system, wherein the marginal cost of risk is not only affected by the risk charge of risk category j but also by other risk categories. However, the marginal BSCR cost is quite different from the U.S. RBC cost of FI securities in equation (3) due to the presence of correlation terms.

We assume that U.S. insurers controlled by foreign entities or persons operate more closely to their parent companies in foreign jurisdictions (e.g., the European Union)[21], and hypothesize that foreign-controlled insurers are less sensitive to marginal RBC costs in their risky FI security investment decisions. To test this hypothesis, we define insurers with more than 50% of foreign ownership as foreign-controlled, and we split insurers into domestically and foreign-controlled insurers.

Table 4 reports the regression results for foreign-controlled and domestically controlled insurers, respectively. The coefficients of *RBC Cost FI* are significant at the 1% level in the domestically controlled subsample. We compare the coefficient of *RBC Cost FI* across these two subsamples using the Chow test and found that the magnitude of the coefficient is significantly larger for domestically controlled insurers, indicating that domestically controlled insurers are more responsive to the RBC cost when formulating their investment decisions. This contrasting behavior between domestically and foreign-controlled insurers provides evidence that the current RBC calculation rule significantly affects risky FI security investments by insurers.

6. Hurricanes Katrina and Sandy as exogenous shocks

Despite the robust results for the relationship between marginal RBC cost and risky investment, there may be concerns about endogeneity. For example, bond investments in a subsequent year is

[21] It can be caused by similar internal control between subsidiaries or branches and their parent firms. Additionally, Solvency II's requirement for the parent company to consolidate the subsidiaries' risk into their own risk profile deters subsidiaries' regulatory arbitrage in the U.S. RBC system.

related to current bond holdings, and current bond holdings affect the RBC cost of FI securities. However, we note that the RBC cost of acquiring FI securities (i.e., the cost of R_1) is not necessarily endogenous, as the operating performance of underwriting business (on the liability side of balance sheets) has an exogenous impact on the RBC cost of FI products (on the asset side).

To further mitigate the endogeneity concern, we use Hurricane Katrina (August 23 to 30, 2005) and Hurricane Sandy (October 30 to 31, 2012) as exogenous shocks. Hurricane Katrina caused USD153.8 billion in damage and killed 1,833 people, and Hurricane Sandy caused USD67.6 billion in damage and killed 159 people.[22]

The two hurricanes provide relatively exogenous settings. First, although hurricanes are fairly predictable, the amount of damage they will cause cannot be predicted. Second, these two hurricanes struck different parts of the country. Hurricane Katrina impacted the Gulf Coast states, while Hurricane Sandy impacted the mid-Atlantic and the northeastern part of the U.S. The New York Stock Exchange even closed for two consecutive days. Historically, the mid-Atlantic and the northeastern part of the U.S. have been less likely than the Gulf Coast states to suffer from hurricane disasters.[23]

6.1. Identification strategy

The significant damage produced by these two hurricanes led the affected insurers to accumulate loss reserves and loss adjustment expense (LAE) reserves to prepare for unpaid losses and their associated expenses.[24] The R_4 risk charge, mainly the product of firm-specific risk weight and the

[22] See NOAA National Centers for Environmental Information (NCEI). U.S. Billion-Dollar Weather and Climate Disasters (2016). https://www.ncdc.noaa.gov/billions/. The cost is CPI-adjusted to 2016 dollars.
[23] Hurricanes Katrina and Sandy are commonly used as exogenous shocks in the literature (Barrot and Sauvagnat, 2016; Bernile et al., 2016).
[24] For example, the Mississippi Farm Bureau Mutual Insurance Co., accounting for approximately 20% of the homeowner market share in Mississippi, tripled its loss reserve in 2005 after Hurricane Katrina.

sum of unpaid loss reserves and LAE reserves, increased exogenously due to the increase in unpaid loss and LAE reserves arising from these two hurricanes.

Figure 1 shows the average loss and LAE reserves development of the hurricane-impacted and non-impacted insurers (the left-hand side for Hurricane Katrina and the right-hand side for Hurricane Sandy). The reported reserve is measured by insurers' unpaid loss and LAE reserves occurring in the current year, scaled by the year-beginning RBC. We define hurricane-impacted insurers as insurers with positive DPW in homeowner lines in the hurricane-impacted states during the hurricane year and as non-impacted insurers otherwise. The scaled reserve's level spiked during the affected years (2005 and 2012) for the hurricane-impacted insurers, whereas the non-impacted firms experienced declines in their reserves. Both the impacted and non-impacted groups show similar trends of reserve development before and after each hurricane shock.

The impact of the exogenous increase in R_4 on the marginal RBC cost of risky investment can be observed in equation (5)—insurers' risky bond investment optimally increases with the decline in the RBC cost of FI securities. This presents affected insurers the opportunity to seek higher investment return at reduced RBC costs of acquiring risky bonds, and we argue this to be an unintended consequence of the square root rule as it incentivizes hurricane-impacted insurers to undertake higher risk in their FI investment portfolios.

As the R_4 risk charge is not directly observable, we use several metrics to identify the insurers that were affected by each hurricane disaster. In insurance literature, homeowner business lines are regarded as being most exposed to hurricane disasters (Cheng and Weiss, 2012). First, we measure an insurer's hurricane exposure by using the proportion of DPW of the homeowner multiple peril line in the affected states[25] to its total DPW (*DPW Exposure*). For example, the *DPW Exposure* for Hurricane Katrina is measured as follows:

$$DPW\ Exposure_i = \frac{\sum_s\ DPW \text{ in homeowner line}_{is,2005}}{DPW_{i,2005}}, s \in \text{Katrina impacted States}^{26}$$

where *i* indicates insurer and *s* indicates state.

DPW Exposure is a flow variable that captures the operation in a certain period. We also use the share of direct unpaid loss and direct unpaid defense cost and expenses reserves in the impacted states (*Loss resv Exposure*) to measure hurricane exposure. This is a stock variable that reflects an insurer's historical exposure accumulated up to the hurricane year. Based on these definitions, we also construct exposure variables for Hurricane Sandy.

We use the difference-in-differences setting to investigate how a change in RBC costs affects insurers' investment behavior by estimating the following model:

$$\begin{aligned} &NoninvtFI\ Net\ Buy_{\mathrm{it}}\ (DownFI\ Net\ Buy_{it}) \\ &\qquad = \alpha_0 + \alpha_i + \alpha_t + \beta_1 Post + \beta_2 Exposure + \ \beta_3 Post * Exposure \\ &\qquad + \gamma_x X_{it-1} + \varepsilon_{it} \end{aligned} \tag{7}$$

The treatment variable (*Exposure*) is a continuous variable ranging from 0 to 1. It measures an insurer's exposure to Hurricanes Katrina and Sandy in 2005 and 2012, respectively. As described

[25] Online Appendix 3 lists the states affected by Hurricanes Katrina and Sandy. We obtain information on the states struck by each hurricane from Table 1 of Barrot and Sauvagnat (2016). They obtain related data from the Spatial Hazard and Loss Database for the United States of America, maintained by the University of South Carolina.

[26] *DPW* in the equation can be replaced by *Loss resv*. Similar to DPW, we use direct premiums earned (*DPE Exposure*) and direct loss and defense cost and expenses (*Loss incur Exposure*) incurred as alternatives. We obtain similar results with these exposure measures.

above, we have two alternative proxies to measure the exposure to each hurricane: *DPW Exposure* and *Loss resv Exposure.* The higher the hurricane exposure, the lower will be the RBC cost to acquire risky FI securities.[27] The post-treatment indicator (*Post*) equals one in 2006 and 2013 for the regressions for Hurricane Katrina and Sandy, respectively, and zero otherwise.

The key variable of interest is the post-exposure interaction term (*Post*Exposure*). The parameter β_3 captures the change in the net purchase of non-investment grade FI securities by the hurricane-impacted insurers relative to the change in the net purchase by the non-impacted insurers. Based on our hypothesis, the estimated coefficient is expected to be positive, indicating that hurricane-affected insurers purchase riskier FI securities as the increase in R_4 caused by the hurricane shock reduces the RBC cost of risky FI securities. We control for firm characteristics, portfolio characteristics and for the firm- and year-fixed effects. We report robust standard errors clustered by insurance companies. We use a 3-year window, beginning 1 year before and ending 1 year after the hurricane.

6.2. Main results

Columns 1 to 4 of Table 5 presents the results for Hurricane Katrina. In columns 1 and 2, we use *DPW Exposure* to measure hurricane exposure and *Loss resv Exposure* in columns 3 and 4 as an alternative exposure measure. We find that the coefficients of the post-exposure terms are positive and significant in columns 1 to 4, indicating that insurers who are more exposed to hurricanes experience a greater increase in their investments of risky bonds and provide further support for our hypothesis. In columns 1 and 2, we observe that, when compared to the non-impacted insurers, the median-affected insurer (with 9.5% of its DPW in homeowner lines in hurricane-affected states)

[27] We also use the dummy variable for the treatment group and obtain similar results.

had 39.6% higher net investments in non-investment grade FI securities and 22.7%[28] higher net purchases of downgraded FI securities.

Columns 5 to 8 of Table 5 presents the results for Hurricane Sandy. Due to the implementation of RBC reform for commercial mortgage-backed security (CMBS) and residential mortgage-backed security (RMBS), we construct dependent variables based on non-MBS FI securities. The estimated coefficients of the post-exposure terms are significant for all non-investment grade FI security regressions, but they are insignificant for downgraded FI security regressions. The magnitudes of the coefficients are consistent with the results of Hurricane Katrina.

One concern is that this risk-taking behavior of affected insurers may be brought about by the loss of capital due to claim payments instead of the marginal RBC cost of a risky bond investment. To disentangle the marginal RBC cost incentive from incentives to recover the loss of capital, we augment equation (7) with two variables to further control for the loss of capital effect, given by the change of surplus scaled by assets (*ΔSurplus*) and the underwriting income scaled by surplus (*Underwrite Gain*). These two variables are also lagged by 1 year in the regression models. In the online appendices 4 and 5, we show that the coefficients on the post-exposure terms have similar magnitudes and significance levels.

Overall, these results are consistent with our expectations for the insurers who were severely impacted by Hurricanes Katrina and Sandy. The RBC costs of acquiring risky FI securities for these insurers decrease exogenously, and they proceed to undertake more risks in seeking profit due to the reduced regulatory cost of risk-taking.

[28] 39.6%=|9.5%*1*0.0126/(-0.00302)|, wherein -0.00302 is the mean of *NoninvtFI Net Buy* in the Katrina sample. 22.7%=|9.5%*1*0.0086/(-0.003586)|, wherein -0.003586 is the mean of *DownFI Net Buy* in the Katrina sample.

6.3. Insurer overall risk

In Section 6.2, we show that hurricane-impacted insurers increase their investment risk. However, some might argue that our results are driven by an alternative hypothesis wherein, after a hurricane, insurers may choose to reduce other risks after increasing their investment risk in a bid to keep their overall risk level constant. In this section, we study whether insurers' overall risks increase after the hurricanes and document results showing that the alternative hypothesis does not hold true.

Following the literature, we measure the aggregate insurer-level risk with two variables (Duchin and Sosyura, 2014; Ljungqvist et al., 2017). The first variable is ROA volatility (*ROA Vol*), the standard deviation of annual comprehensive return on admitted assets over the 3-year period from year *t*-2 to year *t*. The second variable is *z-score*, defined as the comprehensive ROA plus capital asset ratio divided by *ROA Vol.* The z-score is a measure of the distance to insolvency, which aggregates the effects of leverage and asset composition; it approximates for the inverse of default probability, wherein a higher z-score reflects a lower chance of default. We use the comprehensive income to construct these two variables because we want to include the unrealized capital gains from the insurers' investment. Furthermore, we expand our sample by relaxing the restriction that insurers should hold positive non-investment grade FI security positions, as we no longer require transactions of risky FI securities to be our dependent variables.

Columns 1 to 4 of Tables 6 presents the results for Hurricane Katrina. The overall risk is measured by *ROA Vol* and *z-score* in columns 1 to 2 and 3 to 4, respectively. Hurricane exposure is measured by *DPW* and *Loss resv* in columns 1 and 3 and 2 and 4, respectively. Table 6 shows that the coefficients of the post-exposure terms are positive and significant for the ROA volatility measure. These results suggest that insurers with higher exposure to Hurricane Katrina have higher ROA volatility than non-impacted insurers after the hurricane and imply that insurers do not take a risk-reducing strategy to offset the risk-increase in their FI portfolio after a huge loss. In column 3, where we measure the exposure to Hurricane Katrina using DPW, we document a significant difference in the post-hurricane *z-scores* of impacted and non-impacted insurers at a 10% level.

Columns 5 to 8 of Tables 6 present results for Hurricane Sandy wherein the estimated coefficients for the interaction term (which is positive for *ROA Vol* and negative for *z-score*) indicate that firm-level risk would significantly increase for the insurers that suffered from Hurricane Sandy. The interaction terms for the *z-score's* models indicate that the insurers' likelihood of default (the inverse of *z-score*) increased in the year following Hurricane Sandy. In the online appendices 6 and 7, we continue to obtain similar results even after including the additional loss of capital measures.

Collectively, the results reported in Table 5 suggest that insurers impacted by hurricanes choose to increase the risk in their FI portfolios. However, an alternative hypothesis would be that insurers continue and choose to maintain or lower their overall risk level after a hurricane by offsetting the necessarily increased investment risk with a reduction in underwriting risk. Contrary to this alternative hypothesis, Table 6 shows that the overall risk of hurricane-impacted insurers increases more than that of non-impacted insurers after a hurricane shock.

7. Systemic risk and implications for the broader financial system[29]

[29] We thank the referee for this suggestion.

Our result has implications for the broader financial market as the RBC cost, owing to its link with the sale of risky FI securities, may trigger a similar sale during a financial crisis and act as a source of systemic risk.

Some studies have proposed a large number of systemic risk measures[30], while others have focused on more specific channels, including fire sale (e.g., Ellul et al., 2018; Ellul et al., 2011), correlated exposure (e.g., Getmansky et al., 2017), and spillover effect (e.g., Becker and Ivashina, 2015). As most of the insurance companies in our sample are not publicly listed, our analysis focuses on specific channels that do not require data on the firm's stock price.

We show that insurers with a high FI-RBC cost sell similar non-investment grade FI securities during a financial crisis. The results continue to hold even if the high-level of marginal RBC FI cost is caused by the risk charge on the stock investment and underwriting business. This complements the finding by Ellul et al. (2018) that capital regulation and insurers' business decision jointly give rise to asset inter-connectedness; it also adds to the finding by Getmansky et al. (2017) wherein insurers designated as systemically important financial institutions (SIFIs) exhibit sales commonality during the financial crisis.

7.1. Sale similarity and RBC cost

Specifically, we examine the relationship between the net-sale similarity and insurer-pair characteristics. Following Getmansky et al. (2017), the insurer-pair regression model is specified as follows:

[30] A few examples of such studies are systemic expected shortfall (SES) by Acharya et al. (2017), distress insurance premium (DIP) by Huang et al. (2009), CoVar by Adrian and Brunnermeier (2016), Granger causality by Billio et al. (2012), the variance-decomposition contagion measures by Diebold and Yılmaz (2014), and Piccotti (2017). See the survey paper by Bisias et al. (2012).

$$NoninvtFI\ Net\ Sale\ Similarity_{ij,t} = \alpha_0 + \beta_1 High\ RBC\ Cost\ FI\ Pair_{ij,t-1} + \beta_2 Big\ Pair_{ij,t-1} + \beta_3 Small\ Pair_{ij,t-1} + \beta_4 High\ Asset\ Herf\ Pair_{ij,t-1} + \beta_5 High\ RBC\ Ratio\ Pair_{ij,t-1} + \beta_6 NoninvtFI\ Holding\ Similarity_{ij,t-1} + \alpha_t \tag{8}$$

We follow Getmansky et al. (2017) by using the cosine similarity to measure portfolio similarity and net sale similarity at the asset-class level (not security issuer level) between insurer *i* and insurer *j* (termed as an insurer-pair).[31] Please refer to Appendix 2 for a detailed description of the variable construction process. The larger the value of *NoninvtFI Net Sale Similarity*, the more similar FI securities insurer *i* and insurer *j* sell. The standard error is double clustered by year and insurer level.

Following Getmansky et al. (2017), we construct the other pair-wise explanatory variables. The key variable of interest is the indicator variable *High RBC Cost FI Pair*, which takes the value of one if both insurers have *RBC Cost FI* above the sample median and zero otherwise. If the variable of *High RBC Cost FI Pair* has a positive coefficient, then it would indicate that insurer-pairs that both have a high RBC cost are more likely to sell similar FI assets.

We follow Getmansky et al. (2017) by including other controls. We construct two indicator variables—*Big Pair* and *Small Pair,* wherein *Big Pair* (*Small Pair*) equals to one if both insurers

[31] As shown by Getmansky et al. (2017), cosine similarity is well-suited for comparing the "distance" between two vectors and has been widely used in economics, such as text analytics Hanley and Hoberg (2010) and hedge fund portfolio research by Sias et al. (2015).

are large (small) and zero otherwise. We define an insurer as large (small) if it has admitted assets that are above (below) the sample median. We construct an indicator variable *High RBC Ratio Pair*, wherein the *High RBC Ratio Pair* equals to one if both insurers have RBC ratio above the sample median and zero otherwise. Furthermore, we construct an indicator variable *High Asset Concentration Pair*, which equals to one if both insurers have asset Herfindahl index above the sample median and zero otherwise. We calculate the asset Herfindahl index as the sum of the squared ratio of the invested assets over three invested assets categories—bonds, common stocks, and preferred stocks.

In order to investigate the sale similarity between insurers that face high FI-RBC cost during the crisis, we augment Model (8) with an interaction-term *High RBC Cost FI Pair*Crisis*, wherein *Crisis* is an indicator variable that equals to one for years spanning from 2007 to 2010 and zero otherwise.

The results are presented in Panel A of Table 7. In column 1, the coefficient of the *High RBC Cost FI Pair* is insignificant, indicating that insurers with a high RBC cost do not tend to sell similar risky FI securities. However, in column 2, we add the interaction term *High RBC Cost FI Pair*Crisis* and document that the coefficient of the interaction term is significantly positive. This implies that insurers with higher RBC cost tend to sell more similar risky FI securities during a financial crisis, relative to non-crisis years. Furthermore, we test the null hypothesis on whether the coefficient "*High RBC cost FI Pair*Crisis+ High RBC cost FI Pair*" is equal to zero (two-tailed p=0.0692). Our results reject the null hypothesis and imply that insurers with higher RBC cost sell significantly more similar risky FI securities during a crisis, relative to other insurers.

In column 3, we add indicator variables for the insurer pair facing a low RBC cost and found that the coefficient of the interaction term *Low RBC cost FI Pair*Crisis* is significantly negative, while the coefficient of *High RBC cost FI Pair*Crisis* is significantly positive. The results suggest that the behavior of selling similar assets during a financial crisis is not observed among insurers with lower RBC costs.

7.2. High FI-RBC cost caused by the capital charge of other risk categories

We further investigate how the proportion of the FI-RBC cost that can be explained by the capital charge of other risk categories will impact the insurers' sale behavior.

We first regress the marginal RBC cost of FI securities on the capital charge of the other four risk categories[32] and standard underwriting business measures to obtain the predicted value of the FI-RBC cost, *RBC Cost FI Hat*. Similar to Section 7.1, we construct the *High (Low) RBC Cost FI Hat Pair* based on the *RBC Cost FI Hat.* All the other variables are the same as those presented in Section 7.1.

Panel B presents the results. The results are quite consistent with those in Panel A. These results suggest that the high-level of RBC cost of FI securities caused by other risk charges consistently increase the insurers' sale similarity during a crisis, implying that the shocks from the stock investment and underwriting business can transit to FI markets.

[32] We run the following regression to obtain the predicted value:

$$RBC\ Cost\ FI_{it} = \alpha_0 + \alpha_i + \alpha_t + \beta_1 \frac{R_{2,it}}{Surplus} + \beta_2 \frac{\sqrt{{R_{3,it}}^2 + {R_{4,it}}^2 + {R_{5,it}}^2}}{Surplus} + \gamma UnderWrting\ business\ Measures_{it} + \varepsilon_{it},$$

where ${R_3}^2 + {R_4}^2 + {R_5}^2$ is calculated as (firm-level *RBC*- $R_0)^2$ - R_1^2 - R_2^2. The measures of the underwriting business are *Lob Herfindahl, Geo Herfindahl, Longtail,* and *ln(Surplus)* used in our prior main regressions. The results of the first stage regression can be made available by the authors upon request.

8. Additional evidence

We conduct two additional tests. First, as mentioned in Section 4.2, there was an RBC regulatory reform to calculate the risk capital charge for RMBS and CMBS products in 2009 and 2010, respectively. In the earlier sections, apart from the sample for the test on Hurricane Sandy that we analyzed based on only non-MBS FI securities, all other samples are limited to before 2010 to avoid this potential issue. We utilize the most recent data (up to 2015) but focus only on non-MBS FI securities to mitigate the effect of the regulatory reform. In Online Appendix 8, we re-run base regressions corresponding to Tables 2 to 3 and find consistent results. Second, all our earlier results focus only on risky FI security trading, which is related to the risk charge of FI securities. We conduct additional tests to examine the relationship between the marginal RBC cost of stock holdings (*RBC Cost Stock*) and stock investments. Online Appendix 9 consistently shows that insurers with lower RBC costs of equity engage in higher net purchases of common or preferred stocks.

9. Conclusion

We explore the impact of capital adequacy regimes on the risk-taking behavior of firms and use insurance companies as a setting to test our hypotheses. Specifically, we investigate how the composition of regulatory capital and the aggregation approach jointly affect the investment behavior of insurers. The nonlinearity of the RBC formula leads to differences in the marginal RBC cost of acquiring risky assets across different insurance companies and time. Focusing on the marginal RBC cost of risky FI-security investment, we find that insurers facing lower marginal

RBC costs purchase more and sell less risky bonds than insurers with higher marginal RBC costs. Thus, the empirical analyses indicate that insurers actively make their investment decisions in response to their marginal regulatory costs.

Using Hurricanes Katrina and Sandy as exogenous shocks on increasing reserve risk charge, we find that insurers that were severely impacted by the two disasters increased their investment risks and overall firm-level risks. These results highlight the unintended consequence of the current square root rule that embeds the diversification benefit of risk in both the asset and liability of the insurers' balance sheets. Furthermore, we show that the high RBC costs of insurance companies contribute to systemic risk as high RBC costs increase the sale similarity during financial crisis.

We call for a debate on how to adjust for covariance across different risk elements in the design of the RBC regulatory regime effectively. We discussed the square root type adjustment in the U.S. RBC regime, wherein this type of adjustment, or its variation, is also adopted in the minimum continuing capital and surplus requirements (MCCSR) system in Canada and in Solvency II in the European Union. However, we note the use of many alternative approaches for covariance adjustment in other capital regulation regimes. For example, Basel III does not adopt an adjustment for the correlation between market risk, credit risk, and operational risk, but some amount of the diversification benefit is also considered within the risk element.[33] Additionally, the advanced methods in Basel III and Solvency II also recommend the use of an internal model to gauge the financial institutions' overall risk level effectively. We propose that these internal models based on scenario simulation may need to be reviewed with respect to the potential incentives driven by the marginal cost of regulatory capital. Overall, the impact of the diversification benefit adjustment

[33] Covariance adjustment is applied to their standard approach to set the minimum capital requirement for the market risk charge (BIS, 2016).

on financial institutions' risk-taking behavior is underscored, and we provide some evidence to the field.

Appendix 1. Variable descriptions

Dependent variables	
Growth of R_1	(R_1 in year t – R_1 in year t-1)/ R_1 in year t. R_1 is the risk charge in FI investment.
NoninvtFI Sell	The book-adjusted carrying value (BACV) of the non-investment grade fixed-income (FI) securities that insurer *i* sold during year *t*, scaled by the year-beginning BACV of its FI investment.
NoninvtFI Buy	The BACV of non-investment grade FI securities on the purchase date acquired during year *t*, scaled by the year-beginning BACV of insurer *i*'s FI investment.
NoninvtFI Net Buy	Net purchase of non-investment grade FI securities. It is equal to *NoninvtFI buy* minus *NoninvtFI sell*.
NoninvtFI Net Share	The proportion of net purchases of non-investment grade FI securities in the net purchases of all FI securities during year *t*.
DownFI Sell	The BACV of the downgraded FI securities that insurer *i* sold during year *t*, scaled by the year-beginning BACV of its FI investment.
DownFI Buy	The BACV of the downgraded FI securities on the purchase date acquired during year *t*, scaled by the year-beginning BACV of insurer *i*'s FI investment.
DownFI Net Buy	Net purchase of downgraded FI securities. It is equal to *DownFI Buy* minus *DownFI Sell*.
DownFI Net Share	The proportion of net purchases of downgraded FI securities in net purchases of all FI securities during year *t*.
ROA Vol	The standard deviation of the annual comprehensive return on admitted assets over the 3-year period from year *t*-2 to year *t*. Comprehensive return is the sum of net income and unrealized capital gains.
z-score	Comprehensive ROA plus the capital to assets ratio, divided by the standard deviation of the comprehensive ROA, which is then divided by 100.
Insurer-level characteristics	
RBC Cost FI	The risk-based capital (RBC) cost of acquiring risky FI securities, measured at the beginning of year *t*. Equal to $R_1/\sqrt{R_1^2+R_2^2+R_3^2+R_4^2+R_5^2}$ or $R_1/(RBC\text{-}R_0)$. R_0 to R_5 are the components of RBC. RBC is at the firm-level.
RBC Ratio	The RBC ratio at the beginning of year *t*. The ratio of total capital to RBC.
ROE	ROE at the beginning of year *t*. It is equal to the ratio of net income to total surplus.
Ln Surplus	Natural logarithm of insurer *i*'s surplus in $1000 at the beginning of year *t*.
Leverage	Liability divided by assets at the beginning of year *t*.
Mutual	Dummy variable, equal to one if insurer *i* is a mutual firm and zero otherwise.
Group	Dummy variable, equal to one if insurer *i* belongs to a group and zero otherwise.
Lob Herfindahl	Line of business Herfindahl index at the beginning of year *t*.
Geo Herfindahl	Geographical Herfindahl index at the beginning of year *t*.
Longtail	The proportion of direct premiums written (DPW) in long-tail lines of business in total DPW at the beginning of year *t*.
NoninvtFI Position	The share of non-investment grade FI securities in an insurer's total FI investment at the beginning of year *t*.
DownFI Position	The share of downgraded FI securities in an insurer's total FI investment at the beginning of year *t*.

Other Risky Assets	The proportion of invested assets in any of the following asset classes, measured at the beginning of year *t*: common and preferred stocks, nonperforming mortgages, and real estate.
Portfolio Maturity	The average maturity of the insurer's FI portfolio weighted by the BACV at the beginning of year *t*.
Hurricane exposure variables	
DPW	The ratio of insurer *i*'s DPW in homeowner multiple peril lines in hurricane-impacted states to its total DPW in the hurricane year.
DPE	The ratio of insurer *i*'s direct premiums earned (DPE) in homeowner multiple peril lines in hurricane-impacted states to its total DPE in the hurricane year.
Loss incur	The ratio of insurer *i*'s loss incurred in homeowner multiple peril lines in hurricane-impacted states to its total loss incurred in the hurricane year.
Loss resv	The ratio of insurer *i*'s loss and loss-adjusted expense (LAE) reserves in homeowner multiple peril lines in hurricane-impacted states to its total loss and LAE reserves in the hurricane year.
ΔSurplus	The change in surplus scaled by year-end assets. This variable is measured at the beginning of the year.
Underwrite Gain	Net underwriting gains scaled by year-end surplus. This variable is measured at the beginning of the year.
Sale similarity regression	
NoninvtFI Net sale Similarity	Cosine similarity of the net sale of non-investment grade FI securities between insurer *i* and *j*. See Appendix 2 for details.
High RBC Cost FI Pair	One if both insurers have *RBC Cost FI* above the sample median and zero otherwise.
Big (Small)Pair	*Big Pair* (*Small Pair*) equals to one if both insurers are large (small) and zero otherwise. We define an insurer as large (small) if it has admitted assets that are above (below) the sample median.
High Asset Herfindahl Pair	One if both insurers have invested asset Herfindahl index above the sample median, and zero otherwise.
High RBC Ratio Pair	One if both insurers have RBC ratio above the sample median and zero otherwise.
NoninvtFI Holding Similarity	Cosine similarity of the holding of non-investment grade FI securities between insurer *i* and *j*. See Appendix 2 for details.
Crisis	Equals to one for years spanning from 2007 to 2010 and zero otherwise.
Robustness tests	
RBC Cost Stock	The risk-based capital (RBC) cost of acquiring stocks, measured at the beginning of year *t*. Equal to $R_2/\sqrt{{R_1}^2 + {R_2}^2 + {R_3}^2 + {R_4}^2 + {R_5}^2}$.
Growth of R_2	(R_2 in year *t* – R_2 in year *t*-1)/ R_2 in year *t*. R_2 is the risk charge in stock investment.
Stock sell	The fair value of stocks insurer *i* sells in year *t*, scaled by the total invested assets by insurer *i* at the beginning of year *t*.
Stock buy	The fair value of stocks insurer *i* buys in year *t*, scaled by the total invested assets held by insurer *i* at the beginning of year *t*.
Stock Net Buy	The net purchase of stock. It is equal to *Stock buy* minus *Stock sell*.
Stock position	The proportion of common and preferred stocks in the invested assets (the sum of stock and bond investments) at the beginning of year *t*.

Appendix 2. Construction of cosine similarity variables

Holding similarity

For each insurer, we first calculate the proportion of each non-investment grade FI asset class held in an insurer's total non-investment grade FI portfolio at the end of each year, thus creating a vector of portfolio weights (this vector has 60 elements as there are 60 classes of non-investment grade FI securities[34]). We denote this vector as w_{it}, where *i* denotes insurer and *t* denotes year.

Subsequently, we use this vector to construct the variable $NoninvtFI\ Holding\ Similarity$, which measures the cosine similarity between insurer *i* and insurer *j* (termed as an insurer-pair) in year *t*. *NoninvtFI Holding Similarity* is calculated as the dot product of the insurer-pair's portfolio weight vectors normalized by the vectors' lengths, as follows:

$$NoninvtFI\ Holding\ Similarity_{ij,t} = \frac{w_{it} \cdot w_{jt}}{\| w_{it} \| \| w_{jt} \|}$$

Sale similarity

For each insurer, we first create a vector of annul net-sale weight, given by the ratio of the insurer's net sale of non-investment grade FI securities of each asset class to the total net sale of non-investment grade FI securities during year *t* (similar to the aforementioned case, this vector also has 60 elements because there are 60 asset classes). Furthermore, if an insurer does not have a positive net sale of a particular asset class in a given year, then this element would be zero. We denote this net sale vector as s_{it}, where *i* denotes insurer and *t* denotes year. Subsequently, we use this vector to construct the variable $NoninvtFI\ Net\ Sale\ Similarity$, which is calculated as the dot product of the insurer-pair's net sale vectors normalized by the vectors' lengths, as follows:

$$NoninvtFI\ Net\ Sale\ Similarity_{ij,t} = \frac{s_{it} \cdot s_{jt}}{\| s_{it} \| \| s_{jt} \|}$$

[34] According to NAIC schedule D, we define 60 FI asset classes. Specifically, for each FI security, Schedule D provides information about the issuer type (10 types) and the FI issue type (6 types). There are 10 issuer types as follows: "the US Government"; "all other governments"; "states, territories, and possessions"; "political subdivision of states, territories, and possessions"; "special revenue and special assessment obligations"; "public utilities"; "industrial and miscellaneous"; "parent, subsidiaries, and affiliates' bonds"; "hybrid securities"; and "credit tenant loans". There are 6 FI issue types as follows: "issuer obligation," "single-class MBS," "defined multi-class RMBS," "Defined multi-class CMBS," "other multi-class RMBS," and "other multi-class CMBS." If an insurer does not invest in a particular asset class for a given year, then the corresponding weight would be zero.

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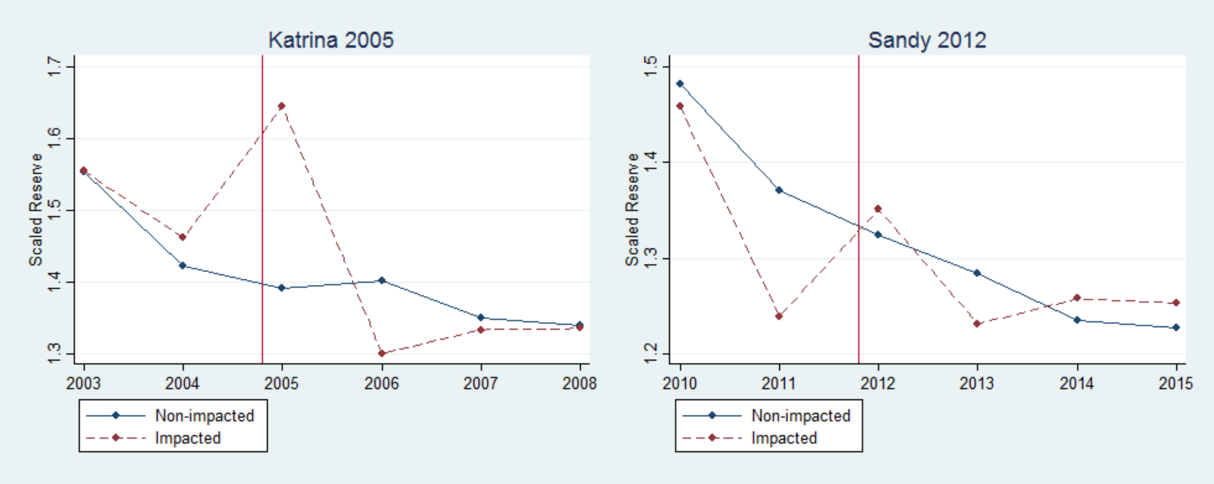
Figure 1. Loss Reserve and Hurricanes



This figure shows how insurers' reserves developed before and after the hurricane. The left figure is for Hurricane Katrina (2005), and the right figure is for Hurricane Sandy (2012). *Reserve* is measured by insurers' unpaid loss and loss-adjusted expenditure reserves of losses incurred in the current year, scaled by the year-beginning risk-based capital. Hurricane-impacted (non-impacted) insurers are those with positive (non-positive) direct premiums written in homeowner lines in hurricane-impacted states during the hurricane year. We show the results for the average insurer in each subsample.

Table 1. Summary statistics

This table presents pooled descriptive statistics of the dependent and independent variables in our regressions. Appendix 1 provides all variable descriptions.

	Count	Mean	S.D.	Min	P50	Max
Dependent variables						
Growth of R1	4226	0.1110	0.4364	-0.7472	0.0400	2.4364
NoninvtFI Sell	4226	0.0068	0.0127	0	0.0006	0.076
NoninvtFI Buy	4226	0.005	0.0168	0	0	0.1151
NoninvtFI Net Buy	4226	-0.0018	0.0186	-0.076	0	0.1151
NoninvtFI Net Share	4191	-0.0031	0.1347	-0.5883	0	0.819
DownFI Sell	4226	0.0056	0.0103	0	0	0.0561
DownFI Buy	4226	0.0024	0.008	0	0	0.0554
DownFI Net Buy	4226	-0.0032	0.0123	-0.0561	0	0.0554
DownFI Net Share	4191	-0.0141	0.0893	-0.4882	0	0.3885
Insurer-level Characteristics						
RBC Cost FI	4226	0.0822	0.1012	0.0064	0.0539	0.6609
RBC Ratio	4226	12.1818	15.8513	1.2308	7.7716	117.8636
Group	4226	0.6209	0.4852	0	1	1
Mutual	4226	0.1706	0.3762	0	0	1
ROE	4226	0.0683	0.131	-0.5319	0.0767	0.4127
Ln Surplus (in thousands)	4226	10.5108	1.453	7.4073	10.4859	13.8468
Leverage	4226	0.5851	0.1716	0.0715	0.6235	0.8667
Lob Herfindahl	4226	0.5346	0.2869	0.1292	0.4661	1
Geo Herfindahl	4226	0.5647	0.3767	0.0425	0.5292	1
Longtail	4226	0.7324	0.2841	0	0.7911	1
NoninvtFI Position	4226	0.0277	0.0407	0.0002	0.0147	0.2673
DownFI Position	4226	0.0251	0.0301	0	0.0157	0.1645
Other Risky Assets	4226	0.1258	0.1486	0	0.073	0.6733
Hurricane Katrina						
DPW Exposure	1302	0.0408	0.1408	-0.0569	0	1.005
DPE Exposure	1302	0.0408	0.1399	0	0	1
Loss incur Exposure	1302	0.0355	0.1334	-0.0006	0	1
Loss resv Exposure	1302	0.0507	0.1644	-0.1018	0	1.907
ROA Vol	4760	0.0417	0.2783	0.0000	0.0202	13.0731
z-score	4760	0.5568	0.9667	0.0042	0.2379	6.8278
Hurricane Sandy						
DPW Exposure	1030	0.0448	0.146	-0.0011	0	1
DPE Exposure	1030	0.0446	0.1448	0	0	1
Loss incur Exposure	1030	0.0341	0.1268	-0.0005	0	1
Loss resv Exposure	1030	0.0503	0.1636	-0.0024	0	0.9971
ROA Vol	5253	0.0306	0.0468	0.0000	0.01809	1.94711

z-score	5253	0.7835	1.5884	0.0036	0.25670	10.50030

Table 2. RBC cost and net purchases of risky FI securities

This table reports the coefficients estimated from the panel regression on the relationship between the RBC cost of FI securities and net purchases of risky FI securities. The sample consists of 4,226 insurer-year observations from 2003 to 2010. Only insurers with no investments in affiliated insurers and positive non-investment grade FI positions at the beginning of year *t* are included. The dependent variable in column 1—*Growth of* R_1—is the growth rate of R_1 in year *t*. R_1 is the risk charge for insurers' FI investment. The dependent variable in column 2—*NoninvtFI Net Buy*—is the net purchase of non-investment grade FI securities, scaled by the year-beginning BACV of its FI holdings. The dependent variable in column 3—*DownFI Net Buy*—is the net purchase of downgraded FI securities during year *t,* scaled by the year-beginning BACV of its FI holdings. The dependent variable in column 4—*Noninvt FI Net Share* —is the proportion of net purchases of non-investment grade FI securities in net purchases of all FI securities during year *t*. The dependent variable in column 5—*DownFI Net Share*—is the proportion of net purchases of downgraded FI securities in net purchases of all FI securities during year *t*. *RBC Cost FI* is the marginal RBC cost of FI securities. All continuous variables are winsorized at the 1st and 99th percentiles. Robust standard errors clustered at the insurer level are reported in parentheses. The superscripts ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

	(1)	(2)	(3)	(4)	(5)
Dependent Variables	*Growth of R1*	*NoninvtFI Net Buy*	*DownFI Net Buy*	*NoninvtFI Net Share*	*DownFI Net Share*
RBC Cost FI	-3.7002***	-0.0504***	-0.0362***	-0.2253***	-0.1346***
	(0.3687)	(0.0192)	(0.0094)	(0.0866)	(0.0467)
RBC Ratio	0.0207***	0.0003***	0.0002***	0.0017***	0.0009**
	(0.0029)	(0.0001)	(0.0001)	(0.0007)	(0.0004)
Group	-0.0390	0.0032	0.0007	0.0024	-0.0252**
	(0.0558)	(0.0026)	(0.0022)	(0.0225)	(0.0128)
Mutual	-0.1067	-0.0013	-0.0013	-0.0282	-0.0075
	(0.0664)	(0.0044)	(0.0037)	(0.0201)	(0.0140)
ROE	0.0809	0.0067**	0.0035*	-0.0058	-0.0106
	(0.0861)	(0.0032)	(0.0021)	(0.0245)	(0.0194)
Ln Surplus	-0.1672***	0.0013	-0.0008	0.0032	-0.0129**
	(0.0483)	(0.0023)	(0.0012)	(0.0109)	(0.0064)
Leverage	0.0090	0.0176**	0.0037	0.0546	-0.0082
	(0.2263)	(0.0079)	(0.0055)	(0.0469)	(0.0307)
Lob Herfindahl	0.1291	0.0010	-0.0013	-0.0498	-0.0114
	(0.1294)	(0.0067)	(0.0037)	(0.0369)	(0.0247)
Geo Herfindahl	0.1238	0.0013	-0.0022	0.0055	-0.0049
	(0.1248)	(0.0047)	(0.0031)	(0.0360)	(0.0196)
Longtail	0.1884	0.0041	0.0000	-0.0585*	-0.0311
	(0.1184)	(0.0064)	(0.0037)	(0.0351)	(0.0219)
Portfolio maturity	-0.0027**	-0.0001*	0.0001	-0.0015**	-0.0000
	(0.0012)	(0.0001)	(0.0000)	(0.0006)	(0.0003)
DownFI Position	3.6774***		-0.1144***		-0.3025***
	(0.4325)		(0.0161)		(0.0852)

NoninvtFI Position	0.4691	-0.1157***		-0.0886	
	(0.5748)	(0.0311)		(0.1542)	
Other Risky Asset	0.2764	0.0398***	0.0126**	0.0350	0.0218
	(0.1953)	(0.0110)	(0.0061)	(0.0515)	(0.0308)
Constant	1.5820***	-0.0294	0.0061	0.0117	0.1784**
	(0.6055)	(0.0256)	(0.0143)	(0.1320)	(0.0811)
Observations	4,226	4,226	4,226	4,191	4,191
R-squared	0.2205	0.0693	0.0846	0.0152	0.0201
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
SE cluster	Insurer	Insurer	Insurer	Insurer	Insurer

Table 3. RBC cost and risky FI securities' net purchase disaggregation

This table reports the coefficient estimated from the panel regression on the relationship between RBC cost of fixed-income (FI) securities and the investment of risky FI securities. We disaggregate the net purchase of risky FI securities (*NoninvtFI Net Buy* or *DownFI Net Buy*) into FI-selling (*NoninvtFI Sell* or *DownFI sell*) and FI-purchasing (*NoninvtFI Buy* or *DownFI Buy*). The sample consists of 4,226 insurer-year observations from 2003 to 2010. Only insurers with no investments in affiliated insurance companies and positive non-investment grade FI positions at the beginning of year *t* are included. Columns 1 and 2 are for non-investment grade FI securities, and columns 3 and 4 are for downgraded FI securities. The dependent variable in column 1—*NoninvtFI Sell*—is the BACV of the non-investment grade FI securities that insurer *i* sold during year *t*, scaled by the year-beginning BACV of its FI investment. The dependent variable in column 2—*NoninvtFI Buy*—is the BACV of non-investment grade FI securities on the purchase date acquired during year *t*, scaled by the year-beginning BACV of insurer *i*'s FI investment. Columns 3 and 4 are for downgraded FI securities. *RBC Cost FI* is the marginal RBC cost of FI securities. All continuous variables are winsorized at the 1st and 99th percentiles. Robust standard errors clustered at the insurer level are reported in parentheses. The superscripts ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

	(1)	(2)	(3)	(4)
Dependent Variables	*NoninvtFI Sell*	*NoninvtFI Buy*	*DownFI Sell*	*DownFI Buy*
RBC Cost FI	0.0136*	-0.0368**	0.0151***	-0.0211***
	(0.0080)	(0.0157)	(0.0047)	(0.0069)
RBC Ratio	-0.0000	0.0003***	-0.0001*	0.0001***
	(0.0001)	(0.0001)	(0.0000)	(0.0000)
Group	-0.0007	0.0025	-0.0008	-0.0001
	(0.0014)	(0.0030)	(0.0014)	(0.0017)
Mutual	-0.0032	-0.0045**	-0.0002	-0.0016
	(0.0044)	(0.0021)	(0.0040)	(0.0014)
ROE	-0.0031	0.0036	-0.0038**	-0.0002
	(0.0019)	(0.0029)	(0.0018)	(0.0014)
Ln Surplus	-0.0005	0.0008	-0.0002	-0.0009
	(0.0011)	(0.0019)	(0.0010)	(0.0007)
Leverage	0.0009	0.0185***	-0.0023	0.0014
	(0.0048)	(0.0070)	(0.0042)	(0.0039)
Lob Herfindahl	0.0002	0.0012	0.0018	0.0005
	(0.0034)	(0.0054)	(0.0029)	(0.0024)
Geo Herfindahl	0.0019	0.0032	0.0021	-0.0001
	(0.0028)	(0.0042)	(0.0028)	(0.0019)
Longtail	0.0005	0.0046	0.0023	0.0024
	(0.0030)	(0.0056)	(0.0031)	(0.0023)
Portfolio Maturity	-0.0001	-0.0002**	0.0000	0.0001**
	(0.0000)	(0.0001)	(0.0000)	(0.0000)
DownFI Position			0.1266***	0.0122
			(0.0114)	(0.0100)
NoninvtFI Position	0.1497***	0.0340		
	(0.0195)	(0.0273)		
Other Risky Assets	-0.0026	0.0372***	0.0001	0.0127***
	(0.0050)	(0.0101)	(0.0042)	(0.0044)
Constant	0.0089	-0.0205	0.0035	0.0096
	(0.0131)	(0.0226)	(0.0116)	(0.0088)
Observations	4,226	4,226	4,226	4,226
R-squared	0.1318	0.0571	0.1652	0.0513
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
SE cluster	Insurer	Insurer	Insurer	Insurer

Table 4. Foreign-controlled- versus domestically controlled insurers

This table reports the coefficients estimated from the panel regression investigating whether the relationship between RBC cost of FI securities and the investment of risky FI securities is different between foreign-controlled- and domestically controlled insurers. Insurers with more than 50% of foreign ownership are considered as foreign-controlled. Only insurers with no investments in affiliated insurance companies and positive non-investment grade FI positions at the beginning of year *t* are included. *RBC Cost FI* is the marginal RBC cost of FI securities. The firm and portfolio controls are the same as those in Tables 2 and 3, including *Group*, *Mutual*, *ROE*, *Ln Surplus*, *Leverage*, *Lob Herfindahl*, *Geo Herfindahl*, *Longtail*, *Portfolio maturity*, *DownFI Position*, *NoninvtFI Position*, *and Other Risky Assets*. All continuous variables are winsorized at the 1st and 99th percentiles. Robust standard errors clustered at the insurer level are reported in parentheses. The superscripts ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

	(1)	(2)	(3)	(4)
	Foreign controlled		**Domestically controlled**	
Dependent Variables	*NoninvtFI Net Buy*	*DownFI Net Buy*	*NoninvtFI Net Buy*	*DownFI Net Buy*
RBC Cost FI	-0.0024	-0.0291*	-0.0625***	-0.0365***
	(0.0185)	(0.0167)	(0.0225)	(0.0105)
Firm controls	Yes	Yes	Yes	Yes
Portfolio controls	Yes	Yes	Yes	Yes
Observations	710	710	3,516	3,516
R-squared	0.2562	0.2480	0.0641	0.0739
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
SE cluster	Insurer	Insurer	Insurer	Insurer
Two sample Chow test (Foreign VS domestically controlled) P-value				
RBC Cost FI	0.0372**	0.7063		

Table 5. RBC cost in Hurricanes Katrina and Sandy

This table reports the coefficients estimated from the DID test investigating the relationship between RBC cost of FI securities and net purchases of risky FI securities. The sample covers the periods from 2004 to 2006 and 2011 to 2013 for Hurricanes Katrina and Sandy, respectively. Columns with odd numbers are for non-investment grade FI securities, and columns with even numbers are for downgraded FI securities. The treatment variable in columns 1-2 and 5-6—*DPW Exposure*—is the ratio of insurer *i*'s DPW in homeowner multiple peril lines in hurricane-impacted states to its total DPW in 2005 and 2012 for Katrina and Sandy, respectively. The treatment variable in columns 3-4 and 7-8—*Loss resv Exposure*—is the ratio of insurer *i*'s loss and loss-adjusted expense (LAE) reserves in homeowner multiple peril lines in hurricane-impacted states to its total loss and LAE reserves in 2005 and 2012 for Katrina and Sandy, respectively. *Post* is a dummy variable that equals to one for the year after the hurricane and zero otherwise. The firm and portfolio controls are the same as those in Tables 2 and 3, including *Group*, *Mutual*, *ROE*, *Ln Surplus*, *Leverage*, *Lob Herfindahl*, *Geo Herfindahl*, *Longtail*, *Portfolio maturity*, *DownFI Position*, *NoninvtFI Position*, and *Other Risky Assets*. All continuous variables are winsorized at the 1st and 99th percentiles. Robust standard errors clustered at the insurer level are reported in parentheses. The superscripts ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Katrina				Sandy			
VARIABLES	*NoninvtFI Net Buy*	*DownFI Net Buy*	*NoninvtFI Net Buy*	*DownFI Net Buy*	*NoninvtFI Net Buy*	*DownFI Net Buy*	*NoninvtFI Net Buy*	*DownFI Net Buy*
Exposure proxy	*DPW*		*Loss resv*		*DPW*		*Loss resv*	
Post	-0.0049**	-0.0036***	-0.0050**	-0.0036***	-0.0042**	0.0002	-0.0042**	0.0002
	(0.0022)	(0.0012)	(0.0022)	(0.0012)	(0.0019)	(0.0008)	(0.0019)	(0.0008)
*Post*Exposure*	0.0126***	0.0086***	0.0112***	0.0068**	0.0155**	0.0037	0.0142**	0.0040
	(0.0034)	(0.0028)	(0.0033)	(0.0029)	(0.0060)	(0.0036)	(0.0056)	(0.0033)
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Portfloio controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,302	1,302	1,302	1,302	1,030	1,030	1,030	1,030
R-squared	0.0940	0.0916	0.0941	0.0910	0.0645	0.0769	0.0646	0.0772
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SE cluster	Insurer	Insurer	Insurer	Insurer	Insurer	Insurer	Insurer	Insurer

Table 6. Overall risks after Hurricanes Katrina and Sandy

This table reports the coefficients estimated from the DID test investigating insurer overall risks. The sample covers the periods from 2004 to 2006 and 2011 to 2013 for Hurricanes Katrina and Sandy, respectively. The sample is larger than the sample in Table 5 because we remove the restriction that insurers should hold positive non-investment grade FI securities' position. The treatment variable in columns with odd numbers—*DPW Exposure*—is the ratio of insurer *i*'s DPW in homeowner multiple peril lines in hurricane-impacted states to its total DPW in 2005 and 2012 for Katrina and Sandy, respectively. The treatment variable in columns with even numbers—*Loss resv Exposure*—is the ratio of insurer *i*'s loss and loss-adjusted expense (LAE) reserves in homeowner multiple peril lines in hurricane-impacted states to its total loss and LAE reserves in 2005 and 2012 for Katrina and Sandy, respectively. *Post* is a dummy variable that equals to one for the year after the hurricane and zero otherwise. The dependent variable in columns 1-2 and 5-6 is *ROA Vol*, the standard deviation of the ratio of comprehensive income to admitted assets (ROA) over the 3-year period from year *t*-2 to year *t*. The dependent variable in columns 3-4 and 7-8 is *z-score*, computed as the sum of ROA and the capital to assets ratio, divided by the standard deviation of ROA, which is then divided by 100. A lower *z-score* indicates a higher risk of default. The firm and portfolio controls are the same as those in Tables 2 and 3, including *Group*, *Mutual*, *ROE*, *Ln Surplus*, *Leverage*, *Lob Herfindahl*, *Geo Herfindahl*, *Longtail*, *Portfolio maturity*, *DownFI Position*, *NoninvtFI Position*, and *Other Risky Assets*. All continuous variables are winsorized at the 1st and 99th percentiles. Robust standard errors clustered at the insurer level are reported in parentheses. The superscripts ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Katrina				Sandy			
VARIABLES	*ROA Vol*		*z-score*		*ROA Vol*		*z-score*	
Exposure proxy	*DPW*	*Loss Resv*	*DPW*	*Loss Resv*	*DPW*	*Loss Resv*	*DPW*	*Loss Resv*
Post	-0.0127	-0.0131	0.1713***	0.1719***	0.0023**	0.0023**	0.0496	0.0540
	(0.0096)	(0.0098)	(0.0307)	(0.0306)	(0.0011)	(0.0011)	(0.0397)	(0.0395)
*Exposure*Post*	0.0261*	0.0292*	-0.1229*	-0.1038	0.0115***	0.0106***	-0.1960	-0.2728**
	(0.0152)	(0.0163)	(0.0661)	(0.0797)	(0.0036)	(0.0031)	(0.1369)	(0.1340)
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Portfloio controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,760	4,760	4,760	4,760	5,253	5,253	5,253	5,253
R-squared	0.0054	0.0054	0.0177	0.0177	0.0120	0.0120	0.0033	0.0036
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SE cluster	Insurer	Insurer	Insurer	Insurer	Insurer	Insurer	Insurer	Insurer

Table 7. Net sale similarity and RBC cost

This table shows how the RBC cost affects the similarity of insurers' sale of non-investment grade FI securities from 2003 to 2010. The observation is at the insurer-pair-year level. The dependent variable is *NoninvtFI Net Sale Similarity*, which is the cosine similarity between insurer *i* and insurer *j*'s net sale of non-investment grade FI securities. In Panel A, *High RBC Cost FI Pair* equals to one if both insurers have *RBC Cost FI* above the sample median. *Crisis* is an indicator variable that equals to one for years from 2007 to 2010 and zero otherwise. *Big Pair* (*Small Pair*) equals to one if both insurers are large (small). We define a large (small) insurer as one with admitted assets above (below) the sample median. *High* (*Low*) *RBC Ratio Pair* equals to one if both insurers have a RBC ratio above (below) the sample median. *High Asset Concentration Pair* equals to one if both insurers have asset Herfindahl index above the sample median. *NoninvtFI Holding Similarity* is the cosine similarity between insurer *i* and insurer *j*'s holding of non-investment grade FI securities. All continuous variables are winsorized at the 1st and 99th percentiles. Robust standard errors clustered at the insurer and year level are reported in parentheses. The superscripts ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

	(1)	(2)	(3)
Panel A		*NoninvtFI Net Sale Similarity*	
*High RBC Cost FI Pair*Crisis*		0.0686**	0.0534**
		(0.0227)	(0.0180)
*Low RBC Cost FI Pair*Crisis*			-0.0580**
			(0.0172)
High RBC Cost FI Pair	0.0039	-0.0408*	-0.0300
	(0.0171)	(0.0198)	(0.0155)
Low RBC Cost FI Pair			0.0416**
			(0.0157)
High RBC Ratio Pair	-0.0291**	-0.0307**	-0.0310**
	(0.0114)	(0.0115)	(0.0121)
Big Pair	0.0085	0.0081	0.0078
	(0.0191)	(0.0194)	(0.0194)
Small Pair	0.0024	0.0028	0.0030
	(0.0228)	(0.0230)	(0.0230)
High Asset Concentration Pair	0.0116	0.0132	0.0136
	(0.0184)	(0.0181)	(0.0176)
NoninvtFI Holding Similarity	0.4721***	0.4727***	0.4730***
	(0.0637)	(0.0633)	(0.0632)
Observations	131,204	131,204	131,204
R-squared	0.2660	0.2676	0.2683
Year FE	Yes	Yes	Yes
SE cluster	Year & Insurer	Year & Insurer	Year & Insurer
Wald Test		*P value*	*P value*
*High RBC Cost FI Pair*Crisis+High RBC Cost FI Pair=0*		0.0692	0.0747
*Low RBC Cost FI Pair*Crisis+Low RBC Cost FI Pair=0*			0.0810

In Panel B, we use the predicted value of *RBC Cost FI*, *RBC Cost FI Hat,* to construct the variable *High (Low) RBC Cost FI Hat Pair. RBC Cost FI Hat* is the portion of RBC *Cost FI* that is explained by other categories of risk charge. It is constructed by regressing *RBC Cost FI* on all other capital charge (R_2-R_5) and standard underwriting business measures (see footnote 32 for the regression model). All other variables are defined similar to those in Panel A. All continuous variables are winsorized at the 1st and 99th percentiles. Robust standard errors clustered at the insurer and year level are reported in parentheses. The superscripts ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

	(1)	(2)	(3)
Panel B	*NoninvtFI Net Sale Similarity*		
*High RBC Cost FI Hat Pair *Crisis*		0.0550**	0.0385**
		(0.0218)	(0.0149)
*Low RBC Cost FI Hat Pair*Crisis*			-0.0431*
			(0.0198)
High RBC Cost FI Hat Pair	0.0238	-0.0162	-0.0038
	(0.0157)	(0.0163)	(0.0119)
Low RBC Cost FI Hat Pair			0.0315
			(0.0176)
High RBC Ratio Pair	-0.0424***	-0.0428***	-0.0425***
	(0.0107)	(0.0105)	(0.0111)
Big Pair	0.0094	0.0093	0.0088
	(0.0189)	(0.0191)	(0.0189)
Small Pair	0.0011	0.0014	0.0017
	(0.0225)	(0.0226)	(0.0224)
High Asset Concentration Pair	0.0120	0.0123	0.0126
	(0.0197)	(0.0197)	(0.0196)
NoninvtFI Holding Similarity	0.4726***	0.4723***	0.4719***
	(0.0635)	(0.0632)	(0.0631)
Observations	131,204	131,204	131,204
R-squared	0.2664	0.2671	0.2676
Year FE	Yes	Yes	Yes
SE cluster	Year & Insurer	Year & Insurer	Year & Insurer
Wald Test		*P value*	*P value*
*High RBC Cost FI Hat Pair *Crisis+High RBC Cost FI Hat Pair =0*		0.0443	0.0416
*Low RBC Cost FI Hat Pair *Crisis+Low RBC Cost FI Hat Pair =0*			0.2819