Adverse Impacts of Regulatory Reforms and Policy Remedies: Theory and Evidence

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Abstract

We develop a portfolio-choice model to investigate how regulatory reforms influence the risk-taking behavior of financial institutions with different capital adequacy levels. The model predicts that either all firms reduce their risk-taking, or there exists a capital-adequacy threshold below which risk-taking increases as regulation becomes more stringent. The Chinese insurance solvency regulatory reform provides a unique natural experiment to test our theory. In 2015, each insurer reported two solvency ratios under the original and the new regulatory systems. The difference between them produces an exogenous and insurer-specific measure of the regulatory pressure shock. Consistent with our theoretical predictions, we find that increasing regulatory pressure induces greater risk-taking for less capital-adequate insurers, an unintended and adverse impact of the regulatory reform. We show that increasing the penalties of insolvency, increasing the risk sensitivity of capital requirements, and reinforcing the qualitative risk assessment are effective policy remedies for this backfiring problem.

Keywords: Risk-Taking; Capital Requirements; Solvency Regulation; Portfolio Choice; Insurance

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1. Introduction

Ensuring continued capital adequacy is lifeblood to financial institutions. Regulators have long been concerned about excessive risk-taking by banks and insurers (Laeven and Levine, 2009; Frame et al., 2019). As a cushion to protect financial institutions from insolvency, risk-based capital-adequacy requirements are the instrument most widely used to regulate risk-taking behavior and ensure the safety and soundness of financial institutions, including banks (Behn et al., 2016; Fraisse et al., 2020) and insurers (Ellul et al., 2011; Lin et al., 2014). The framework of capital-adequacy regulation has already been in place for some time in major financial markets. Continuous reforms have been introduced to further improve the regulation and firms' risk management, such as the Basel III reform in the banking sector and the Solvency II reform in the insurance sector. The following questions arise naturally: How should we evaluate the effectiveness of a capital regulatory reform? Can regulators always reduce the risk-taking behavior of financial institutions by setting more stringent capital requirements? If not, what are potential remedies for the unintended consequence of regulatory reforms?

To resolve these questions, we investigate, both theoretically and empirically, the impact of a regulatory pressure shock on the risk-taking behavior of financial institutions. We propose a portfolio-choice model that allows for both non-risk-based and risk-based capital regulations and sheds light on the underlying mechanism that links firms' capital adequacy, their risk-taking behavior, and regulatory pressure. Formally, we consider a setup in which firms with different capital-adequacy levels choose between a risky investment and a safe investment. The safe investment yields a deterministic return, whereas the risky investment may generate a higher or a lower return than the safe investment. A regulator calculates a firm's capital-adequacy ratio (or equivalently, solvency ratio) based on its portfolio composition and balance sheet. The firm is subject to regulatory intervention and incurs a regulatory cost if its capital-adequacy ratio or solvency ratio falls below a predetermined threshold.

We demonstrate that the stringency of the capital-regulation policy is crucial to firms' optimal portfolio choice (i.e., their optimal risk-taking behavior). When the regulation is moderate, a firm with a higher (lower, respectively) capital-adequacy level would take more (less, respectively) risks. Interestingly, our model predicts a U-shaped relationship between firms' risk-taking and their capital-adequacy levels when the regulation is sufficiently stringent. Based on firms' optimal investment strategies, we further show that two patterns can arise upon the introduction of a more stringent regulatory policy: either (i) all firms uniformly reduce their risk-taking, or (ii) there exists a capital-adequacy threshold below which (above which, respectively) firms' risk-taking increases (decreases). The intuition is as follows. Under a moderate regulation, no firm would incur a regulatory cost as long as the realized return of the risky investment is high, and thus firms are only concerned with their solvency condition in the case where the return of the risky investment is low. Because a more capital-adequate firm is able to bear greater risk, it would invest more in the risky portfolio in the optimum. However, when the capital regulation becomes sufficiently stringent due to a stricter regulatory reform, firms with lower capital adequacy cannot avoid regulatory cost when the return of the risky investment is low regardless of the risk they take, and thus they turn to concern about their solvency condition when the risky investment succeeds. These firms, pushed to the wall by the stricter regulatory reform, take desperate measures and invest aggressively in the risky portfolio; and the nonmonotonic relationship results, bringing about the aforementioned adverse impact.

We then empirically test our theoretical predictions. Empirically identifying the effect of a capital regulation is challenging for several reasons. First, the capital adequacy of financial institutions is endogenously determined. The risk structure of asset and liability portfolios determines the amount of required capital and the capital-adequacy ratio (or the solvency ratio) in a risk-based capital regulatory system. To address the endogeneity problem, an exogenous event is expected to disentangle the impact of capital regulation on risk-taking from its reverse causality (Behn et al., 2016). Second, many factors influence the risk-taking behavior of financial institutions, including business cycles, strategy changes driven by management or major shareholder changes, changes on the demand side, etc. Therefore, an ideal exogenous event for empirical identification should have a short duration, as a shock to financial institutions, to minimize the impact of other risk-taking determinants. Third, the impacts of capital regulation are likely to vary for financial institutions with different characteristics, for instance, different initial capital-adequacy levels (Klomp and Haan, 2012; Mankaï and Belgacem, 2016). The empirical design should allow for such heterogeneous effects.

The Chinese solvency regulatory reform in the insurance sector creates a unique natural experiment for analysis of the effectiveness of capital regulation and the impacts of regulatory reform. Insurance companies usually have a wider array of choices than banks when they formulate their asset-risk structures; they actively assume underwriting risks on the liability side while banks do not. As the third largest insurance market in the world, China shifted from its first-generation volume-based solvency capital regulation (hereafter "Chinese Solvency I") to its second-generation China Risk Oriented Solvency System (hereafter "C-ROSS") from 2013 to 2015. This tight transition schedule minimizes the chance that changes in insurers' risk-taking behaviors were driven by other considerations. In 2015, the pilot implementation year, every insurer operating in China was required to report its solvency ratios under both Chinese Solvency I and C-ROSS. C-ROSS was for information only in 2015 and became effective and replaced Chinese Solvency I in January 2016. The difference between the two solvency ratios produces an accurate and insurer-specific measure of capital shock purely driven by the regulatory reform. This unique scenario allows us to capture the exogenous changes of regulatory pressure for each and every affected insurer.

Our empirical analyses yield findings that adhere to our theoretical predictions. We document that the impact of a capital shock on insurers' risk-taking behavior depends on the insurers' capital-adequacy levels. For capital-adequate insurers whose solvency requirements are far above the regulatory threshold, a marginal increase (decrease, respectively) in regulatory pressure leads to less (more, respectively) risk-taking. These results are consistent with the regulatory intention and with existing insurance literature (Cheng and Weiss, 2013; Lin et al., 2014; Mankaï and Belgacem, 2016; Chen et al., 2019). More interestingly, we show that a marginal increase (decrease, respectively) in regulatory pressure leads to more (less, respectively) risk-taking for insurers whose solvency ratios are low and close to triggering regulatory intervention. For these less-solvent insurers, a more stringent regulation backfires and induces more risk-taking. The results are counter to the regulatory intention (CIRC, 2012). To our best knowledge, we are the first to theorize and empirically document this potential adverse impact that regulatory pressure may have on risk-taking behavior in life and nonlife insurance industries.

Our findings have important policy implications for the design of regulatory reforms: Any reforms that result in higher capital requirements should always be coupled with regulatory actions to mitigate the resultant adverse effect. In Section 6, we show how the following three remedies potentially fulfill this purpose: (i) increasing penalties for insolvent institutions; (ii) increasing the risk sensitivity of capital requirements; and (iii) reinforcing the qualitative risk assessment (i.e., Pillar II) of capital regulation.

Contribution and Relation to Literature Our paper is naturally linked to the theoretical literature that studies the impact of capital regulation on the risk-taking behavior of financial institutions. This literature offers mixed predictions. In the banking sector, Lam and Chen (1985), Furlong and Keeley (1989), Keeley (1990), Campbell et al. (1992), Thakor (1996), and Repullo (2004) show that minimum capital requirements reduce banks' risk-taking. In the insurance sector, Cummins and Sommer (1996) and Lin et al. (2014) develop an option-pricing model and predict a negative impact of regulatory pressure on insurers' risk-taking. In contrast, Koehn and Santomero (1980), Kim and Santomero (1988), Gennotte and Pyle (1991), Besanko and Kanatas (1996), Blum (1999), and Lundtofte and Nielsen (2019) argue that minimum capital regulation may cause more portfolio risks because a binding capital constraint may distort a bank's lending, investment decisions, its marginal return of risk-taking, and/or the risk and value calculations for the bank's assets. Relatedly, Bahaj and Malherbe (2020) show that despite that capital is costly for banks, higher capital requirements need not lead to less lending (and thus risk taking if the marginal loan is riskier). Calem and Rob (1999) develop an infinite-horizon model to investigate banks' dynamic portfolio choices and reconcile the opposite theoretical predictions. They generate a numerical solution to the model, which suggests a U-shaped impact of the capital-adequacy ratio on banks' risk-taking behavior.

We contribute to the existing theories of financial capital regulation in three ways. First, complementing Calem and Robb (1999), we develop a unified framework that points to the possibilities of both an increasing and a U-shaped relationship between firms' capital-adequacy position and their risk-taking behavior, and identify conditions for each possibility to occur. We show in Proposition 1 that an increasing relationship arises when the regulation is moderate and a U-shaped relationship results when the regulation is sufficiently stringent. The stringency of a regulation is defined by the minimum capital to liability ratio and its relative position to the return of the safe investment. These conditions provide novel insights on risk-taking incentives of financial institutions in the presence of capital regulation and potentially guide future capital regulatory reforms. Second, because our model enables us to fully characterize firm's optimal portfolio choice in the equilibrium under a capital regulation, we are able to analytically investigate the consequences of capital regulatory reforms. In particular, we investigate in Proposition 2 comparative statics for two types of regulatory reforms: (i) change in the capital-adequacy threshold and/or (ii) change in the formula of capital-adequacy ratio or solvency ratio. Third (and importantly), previous studies impose certain structures that are specific to either the banking or the insurance sector to model regulations (e.g., Calem and Rob, 1999; Lin et al., 2014). In contrast, we abstract away the specificity and model the capital regulation in a general way. We thus believe that the results and insights obtained in our model are robust across the banking and insurance sectors.

Existing empirical studies use the level of capital adequacy to approximate the degree of regulatory pressure and use the changes of capital-adequacy ratios or solvency ratios between two adjacent years to approximate the changes of regulatory pressure. A higher (lower) capital ratio indicates a lower (higher) regulatory pressure; and an increase (decrease) in the capital ratio implies a lower (higher) regulatory pressure. They examine the correlation between capital ratios (or capital requirements) and the amount of risk-taking in the banking sector (e.g., Shrieves and Dahl, 1992; Jacques and Nigro, 1997;

Rime, 2001) or in the insurance sector (e.g., Cummins and Sommer, 1996; Baranoff and Sager, 2002; Shim, 2010; Cheng and Weiss, 2013; Lin et al., 2014; Mankaï and Belgacem, 2016).

Some of these studies use simultaneous-equation models to account for the endogeneity of capital-adequacy ratios or solvency ratios (Shim, 2010; Mankaï and Belgacem, 2016). Still, it is difficult to disentangle the causal effect of regulatory pressure on risk-taking from its reverse causality. Some studies use the inherent differences in one regulatory scheme to construct exogenous variations of regulatory pressure on different financial institutions, for example, whether the bank is subject to regulatory actions (Peek and Rosengren, 1995a) and whether the institution is a resident bank or a foreign branch (Aiyar et al., 2014). However, this identification strategy may be biased and hard to interpret as the regulation-targeted banks are not randomly chosen (Fraisse et al., 2020). Other studies explore economic or natural events, or regulatory reforms, as exogenous shock that cause the variations in regulatory pressure such as the "capital crunch" in New England due to the implementation of Basel I (Peek and Rosengren, 1995b), the introduction of Troubled Asset Relief Program after the 2008 financial crisis (Eckles and Hilliard, 2015), the shock of the Lehman Brothers bankruptcy (Behn et al., 2016), the dynamic provisioning experiment in Spain (Jiménez et al., 2017), Hurricane Katrina and Hurricane Sandy (Chen et al., 2019), and the MBS capital requirement reform in the U.S. insurance industry (Becker et al., 2020).

Advancing the existing literature, the exogenous shock in our paper not only constructs one treatment group and one control group, but also accurately measures the degree of positive and negative treatment for each and every insurer. We move the existing empirical literature forward by capturing a reform-driven regulatory pressure change (i.e., a capital shock) that is exogenous, unbiased, and insurer-specific. Further, to the best of our knowledge, most previous research concentrates on mature markets, with one notable exception provided by Campbell et al. (2015), who employ loan data in India to analyze the impact of regulatory changes on mortgage risk. We provide new evidence that allows for dynamic causal inferences about the impacts of insurance solvency regulation from another representative emerging market comprising large, medium, small, and start-up players. Our analyses complement existing cross-country and mature-market evidence (Hendricks and Hirtle, 1997; Barth et al., 2004) and reinforce the assertion that the impact of capital regulation on risk-taking of financial institutions should not be market dependent (Laeven and Levine, 2009).

Our paper also contributes to the literature on the differential impact of solvency capital regulation on diverse insurers (Ellul et al., 2011; Cheng and Weiss, 2013; Lin et al., 2014; Mankaï and Belgacem, 2016).

Ellul et al. (2011) analyze a specific type of portfolio risk adjustment---fire sales of downgraded corporate bonds---induced by regulatory constraints imposed on insurers. They show that insurers with low risk-based solvency ratios (i.e., with high regulatory pressure) are more likely to sell downgraded bonds than high solvency-ratio insurers. Cheng and Weiss (2013), Lin et al. (2014), and Mankaï and Belgacem (2016) confirm the dependency of solvency position in the insurance sector. They suggest that the impact of regulatory pressure on insurers' risk-taking is in one direction, though the impact can be weaker for insurers with low regulatory pressure. Our empirical findings document for the first time a U-shaped impact of regulatory pressure on risk-taking in the life and nonlife insurance industries.

The rest of the paper is structured as follows. Section 2 introduces the institutional background. Section 3 presents a portfolio-choice model used to derive our propositions and hypotheses. Section 4 describes our empirical strategy and data. Section 5 presents the empirical results. Section 6 discusses policies that may mitigate the unintended adverse impact of regulatory reform. Section 7 concludes. All proofs of propositions appear in Appendix A.

2. Institutional Background

The concept of appropriate minimum levels of capital for different categories of bank assets was introduced in the U.S. in the mid-1950s; the capital (to asset) ratio was then implemented in 1981 (VanHoose, 2007). The Basel Accords (Basel I) initiated the globally coordinated efforts to account for the heterogeneity of risks in different sets of bank assets in 1988. Basel II introduced the three-pillar regulatory framework and bank internal models in 2006. Motivated by the 2008 financial crisis, Basel III was finalized in 2017. It focused on increasing capital adequacy requirements, increasing the costs of risk-taking, and other regulatory indicators in addition to the capital-adequacy ratio. In the insurance sector, the concept of solvency capital requirements was introduced in the 1970s in the U.S. It has been undergoing reforms in major insurance markets since the 1990s, including the Risk-Based Capital reform in the U.S. (RBC, 1994), the Solvency II reform in the European Union (Solvency II, 2015), and the reform of China Risk-Oriented Solvency System (C-ROSS, 2015). These solvency regulatory reforms aim at improving detection, measurement, and control of the risk-taking behaviors of financial institutions (VanHoose, 2007), and in principle, do not target or favor particular institutions.

C-ROSS is a three-pillar risk-based solvency regulatory system that conforms to the international Insurance Core Principles (IAIS, 2018). According to Chinese Solvency I, the minimum capital requirement is represented as a percentage (16% or 18%) of the past year's premiums or reserves (CIRC, 2003). This requirement does not distinguish between various classes of asset risk. The reform updated the rules concerning the capital charges for asset risk (e.g., market and credit risks), product risks, and the diversification benefits between them (Fung et al., 2018; Liu et al., 2019). The C-ROSS reform fundamentally changed the way to calculate the solvency capital requirement for each insurer from volume-based approach to risk-oriented approach, which significantly changed the amount of capital requirements for most insurers and reshaped their behaviors.

Solvency regulatory reforms usually take a long time. It took the U.S. market four years (1990-1994) to shift from the fixed capital standards to RBC standards, and the European Union (EU) eight years (2007-2015) to move from Solvency I to Solvency II. Long transition periods give insurers ample time to adapt to new solvency capital regulations before its formal implementation occurs. These reforms cannot be considered as unexpected shocks to market players, and it is difficult to empirically evaluate their impact.

Compared to the aforementioned reforms, the Chinese solvency regulatory reform had a very short transition window. It was completed in less than two years (2013-2015). The first draft of the C-ROSS framework was released by the regulator in May 2013. A draft set of regulation was published in February 2015, followed by a pilot implementation for all insurers operating in China in the same year. After the 2015 pilot, C-ROSS was formally implemented and became effective nationwide on January 1, 2016 with no material amendments from the pilot version. During the reform process and the pilot year of 2015, insurers were unlikely to make portfolio adjustments based on the new regulation because (i) they were uncertain what the new regulation would entail and when it would become effective, and (ii) in 2013-2015, the Chinese Solvency I regulation remained in force and had a stronger influence on insurers than the pending new regulation (Zhao, 2017).

In 2015, each insurer was required to report its solvency ratios under both the in-effect Chinese Solvency I and the for-information-only C-ROSS. The difference between the two solvency ratios produces an accurate and insurer-specific measure of capital shock. The regulatory pressure increased (i.e., the solvency ratio under C-ROSS was smaller than that under Chinese Solvency I in 2015) for about two thirds of insurers and decreased for the other third due to this reform. This capital shock is exogenous to market players because the short transition period of the reform left insurers little time to adjust their portfolio structure before its formal implementation, and thus the risk structure of each insurer's portfolio can be considered predetermined.

C-ROSS is considered to be a more stringent regulatory reform. The Chinese regulator explicitly stated at the beginning of the reform that C-ROSS intends to reinforce solvency regulation and to effectively control and mitigate the risks of the insurance industry (CIRC, 2012). This is consistent with our finding that C-ROSS increases regulatory pressure on average for the Chinese insurance industry (see Table 2) and for majority of market players.

It is worth noting that there was no material change in the Chinese insurance guarantee fund (founded in 2008) or in the insurance accounting rules during the sample period (2013-2017). The fixed rate (which is based on the premium volume) and the operating model of the fund remained stable. The previous reform of insurance accounting rules occurred in 2009 (Ministry of Finance, 2009). Further, there are no major changes in the environment of market discipline during the sample period. The yearly gross premium growth in the Chinese market from 2013 to 2017 were 17.5%, 20.0%, 27.5%, and 18.2%, suggesting a healthy development pattern for an emerging market. We do not record any major pressure changes due to liquidity constraints and/or changes in policyholders' behavior during the sample period.

3. A Theoretical Model

In this section, we develop a two-period portfolio-choice model to investigate (i) the relationship between the capital adequacy of financial institutions and their level of risk-taking given a capital regulation policy; and (ii) the impact of a regulatory reform on this relationship.

3.1 Model and Preliminaries

A firm (either a bank or an insurer) is endowed with capital $\psi \in (0,1)$ and liability $1-\psi$, which are exogenous and vary across firms. The firm's investment is funded through its capital and liability. The investment can be broadly interpreted as allocation of resources to potential business opportunities. For instance, it could be an insurer's investment portfolio choice between assets of different risks (e.g., bonds vs. equities) or a bank's loan portfolio choice between borrowers with different credit risks. It can also be interpreted as an insurer's insurance portfolio decision between product lines of different risks (e.g., motor insurance vs. property insurance). In what follows, we adopt the first interpretation and assume that the firm makes the investment decision on the asset side. In Appendix B1, we show that the model can be easily adapted to the second interpretation.

In the first period, the firm chooses a portfolio composition consisting of $R \in [0,1]$ units of the risky asset and $1-R$ units of the safe asset. In the second period, the return of the asset investment is realized, and the firm may incur a constant regulatory cost $c > 0$ if regulatory action is taken against the firm.[1] We show that our results are robust to non-constant regulatory costs in Section 3.3. For the sake of simplicity, we do not model period-1 regulatory cost. One could assume that firms in our setup have incurred the period-1 regulatory cost (if any) and are at the stage of making their investment decision, which will influence their future probability of being subject to regulatory actions.

The safe portfolio earns a deterministic gross return $x > 1$ per unit of asset. The risky portfolio generates a random return to the firm. Specifically, the risky portfolio may yield two outcomes: (i) a gross return of $y > x$ per unit of risky asset; or (ii) zero gross return. We use $s \in \{0,1\}$ to indicate the outcome of investing in the risky asset: $s = 1$ and $s = 0$ refer to the situations where the gross return is y and 0, respectively. Without loss of generality, we assume that $\Pr(s = 1) = 1 - \Pr(s = 0) = 1/2$. This assumption is innocuous, and our results remain unchanged for all $\Pr(s = 1) \in (0,1)$. We make the following assumption about the returns of the two portfolios:

Assumption 1 $\quad y/2 > x$.

Note that $y/2$ is the expected return per unit of the risky asset. Assumption 1 simply states that the risky portfolio generates an expected payoff that is strictly higher than that of the safe portfolio, which creates the tradeoff between risk-taking and expected return for firms.

The return of firm's asset s is realized in the second period, and the accounting earnings can be derived accordingly. We normalize the cost of capital and the return of liability to zero for simplicity. Fixing a firm's investment strategy $R \in [0,1]$ and the realized outcome of the risky asset $s \in \{0,1\}$, the firm's profit, denoted by $\pi(s, R)$, can be derived as

$$\pi(s, R) = ysR + x(1 - R) - 1.$$

Firm's capital in the balance sheet is thus updated to $\psi + \pi(s, R)$,[2] and liability remains at $1 - \psi$ (Li, 2017). The firm's balance sheet in each period is summarized in Table 1:

[1] Regulatory costs can be monetary or non-monetary. For instance, the cost is monetary if the regulator charges a fine to the firm, and non-monetary if the regulator restrains certain business development plans or temporarily takes over the management of the firm. Such a cost can also be interpreted as opportunity cost, for example, the reputational cost that may affect the market value and future business development.

[2] Note that a firm can only change its period-2 capital position internally through its investment. This allows us to focus on the firm's risk-taking incentive. In practice, a firm can also raise its capital through internal capital markets of financial groups and/or external financing. It is useful to interpret ψ in our model as the amount of capital after external capital financing, if any.

Table 1 Firm's Balance Sheet

	$t = 1$	$t = 2$
Capital (K)	ψ	$\psi + \pi(s, R)$
Liabilities (L)	$1 - \psi$	$1 - \psi$
Assets (A)	1	$1 + \pi(s, R)$

The firm's capital adequacy is measured by $K/f(A, L, R)$, which corresponds to the capital-adequacy ratio in the banking sector or the solvency ratio in the insurance sector. The function $f(A, L, R) > 0$ is the formula that the regulator uses to determine a bank's risk-weighted assets or an insurer's minimum capital requirement based on its assets A, liabilities L,[3] and investment strategy R. The firm is subject to a capital regulation. Regulatory intervention is triggered and the firm incurs a regulatory cost $c > 0$ if the capital-adequacy ratio or the solvency ratio $K/f(A, L, R)$ falls below a predetermined threshold $\tau > 0$. The firm incurs no regulatory cost otherwise.[4] A capital regulation is fully characterized by $\langle f(\cdot,\cdot,\cdot), \tau \rangle$.

We assume that the formula $f(A, L, R)$ satisfies the following properties:

Assumption 2 $\partial f/\partial A > 0, \partial f/\partial L > 0, \partial f/\partial R \geq 0, and\ f(\lambda A, \lambda L, R) = \lambda f(A, L, R)\ \forall \lambda > 0.$

The first two conditions in Assumption 2 state that the risk-weighted assets or the minimum capital requirement would increase if a firm holds more assets or liabilities. The third condition states that the amount of risk-weighted assets or required capital is weakly increasing in a firm's risk-taking. Under a non-risk-based capital regulation, the amount of assets or required capital is independent of a firm's risk structure, i.e., $\partial f/\partial R = 0$ for all $R \in [0,1]$. The last condition requires that $f(\cdot,\cdot,\cdot)$ exhibit homogeneity of degree one. The condition indicates that the capital-adequacy ratio (solvency ratio) is size-neutral: Fixing the investment strategy R, the risk-weighted assets (or minimum capital requirement) varies in proportion to the firm size.[5]

Recall that a firm is under regulatory intervention if

[3] Liability plays a minor role in determining a bank's risk-weighted assets and is more important for an insurer's minimum capital requirement.

[4] We assume that regulatory intervention is not triggered when $K/f(A, L, R) = \tau$. This assumption is consistent with the practice. Technically, it guarantees the existence of maxima for the insurer's optimization problem.

[5] The assumption of size neutrality is consistent with our empirical observation. We categorize insurers in life and nonlife samples into three groups based on their total assets. In 2016, the year in which C-ROSS became effective, the average solvency ratios between small, medium, and large insurers were not significantly different from each other. The p-value of F-test is 0.29 (0.27) in the nonlife (life) sample. The results are similar in 2017, with p-value of 0.64 (0.16) for the nonlife (life) sample. These results suggest that risk-based solvency regulation is not biased towards insurers of particular sizes.

$$\frac{K}{f(A,L,R)} < \tau.$$

When $K > 0$, it follows from Assumption 2 that the above condition can be simplified as[6]

$$\frac{K}{f(A,L,R)} = \frac{1}{f(A,L,R)/K} = \frac{1}{f\left(1+\frac{L}{K},\frac{L}{K},R\right)} < \tau.$$

Denote the unique solution to $f(1+1/\eta\,, 1/\eta\,, R) = 1/\tau$ by $\eta(R)$.[7] The above analysis implies that a firm would incur a regulatory cost if and only if

$$K/L < \eta(R).$$

Intuitively, $\eta(R)$ specifies the minimum capital-liability ratio that is required to avoid regulatory intervention.

Two clarifying remarks are in order. First, the impacts of both τ and $f(\cdot,\cdot,\cdot)$ are encapsulated in the threshold $\eta(\cdot)$. Therefore, a regulation reform that varies the threshold-solvency condition τ or the formula used to derive a firm's risk-weighted assets or required capital $f(\cdot,\cdot,\cdot)$ would result in a change in the threshold capital-liability ratio $\eta(\cdot)$. Both types of reforms are common in practice. For example, the solvency regulatory reforms in the insurance sector usually update the formulation of minimum capital requirements. In the banking sector, the change from Basel II to Basel III raised the capital-adequacy threshold from four percent of the core capital-adequacy ratio to five to six percent in 2010, and later updated the formulation of risk-weighted assets in 2017. All these reforms can be modeled by the change of $\eta(\cdot)$ in our setup. Second, the threshold ratio η depends on a firm's investment decision R. Assumption 2 implies that $\eta(R)$ is weakly increasing in R. In other words, all other things being equal, greater risk-taking is associated with a weakly higher threshold on the capital-liability ratio.

To obtain more mileage, we impose the following regularity condition on $\eta(\cdot)$

Assumption 3 $\;d^2\eta/dR^2 \geq 0\ \forall R \in [0,1]$ *and* $\eta(1) < y - 1$.

The weak convexity of the threshold capital-liability ratio $\eta(\cdot)$ captures the idea that a capital regulation $\langle f(\cdot,\cdot,\cdot), \tau\rangle$ restrains risk-taking: The marginal increase in a firm's minimum capital-liability ratio required to avoid the regulatory cost weakly increases as a firm increases its risk-taking behavior. Note that

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[6] It is evident that $K/f(A,L,R) < \tau$ holds when $K \leq 0$, or equivalently, when a firm becomes bankrupt. In Section 3.3 and Appendix B2, we assume that firms incur a cost that is greater than the regulatory cost if bankruptcy occurs, and show that our results remain unchanged.

[7] We implicitly assume that a solution exists for any $R \in [0,1]$ for simplicity. Sufficient conditions for its existence are $\lim_{x\to 0} f(1+x,x,R) = 0$ and $\lim_{x\to\infty} f(1+x,x,R) = \infty$. Uniqueness follows directly from Assumption 2.

Assumption 3 does not exclude the possibility of a non-risk-based capital regulation, in which case $\eta(R)$ is constant over R and $d^2\eta/dR^2 = 0$. Further, it is useful to point out that weak convexity of $\eta(\cdot)$ is a simplifying assumption; it is possible that the global convexity of $\eta(\cdot)$ is violated for some intervals of R in practice (e.g., the special long-term equity investment rules in C-ROSS, Fung et al., 2018). We conjecture that our results remain intact given that the interval is not excessively large.

The condition $\eta(1) < y - 1$ ensures that the risk-restraint effect of regulation is not excessive in the sense that no firms would be subject to regulatory intervention in the most favorable scenario, that is, when firms solely invest in the risky asset (i.e., $R = 1$) and the realized return is y (i.e., $s = 1$).[8]

3.2 Analysis

Now we are ready to delineate the firm's problem. Risk-neutral firms[9] choose an asset portfolio $R \in [0,1]$ to maximize the expected return from its assets net of the expected regulatory costs. More formally, the firm solves the following optimization problem:

$$\max_{R\in[0,1]} \Pi(R) := \frac{1}{2} yR + x(1-R) - c \Pr\left(\frac{\psi + \pi(s,R)}{1-\psi} < \eta(R)\right).$$

By Assumption 1, a firm would invest only in the risky asset (i.e., $R = 1$) in the absence of capital regulation (i.e., $c = 0$).

Before we proceed, it is useful to take a closer look at the period-2 capital-liability ratio in the firm's objective, which can be written as

$$\frac{\psi + \pi(s,R)}{1-\psi} = \frac{ys - x}{1-\psi} R + \left(\frac{x}{1-\psi} - 1\right).$$

The above reformulation sheds lights on the firms' costs and benefits under different outcomes of risky assets when capital regulation is in place (i.e., $c > 0$). Specifically, when the realized gross return per unit of risky assets is y (i.e., $s = 1$), the capital-liability ratio is strictly increasing in R. Therefore, more investment in the risky assets leads to an increase in firms' capital-liability ratio. In contrast, when the realized gross return per unit of risky assets is 0 (i.e., $s = 0$), more investment in risky assets would reduce firms' capital-liability ratio.

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[8] To see this, a firm's equity is updated to $K = \psi + y - 1$, and its liability is $L = 1 - \psi$ when $R = 1$ and $s = 1$. The firm would not be subject to regulatory intervention if $(\psi + y - 1)/(1 - \psi) \geq \eta(1)$. It can be verified that the inequality holds for all $\psi \in (0,1)$ if $\eta(1) < y - 1$.

[9] Risk neutrality allows us to separate risk effects that are due to firms' risk choice from risk effects that are due to the risk aversion of managers, creditors, and investors, and is commonly assumed in the literature (e.g., Blum, 1999; Calem and Rob, 1999; Lin et al., 2014; and Li, 2017).

Optimal Portfolio Structure Next, we characterize firm's optimal asset decision with respect to its initial capital adequacy ψ, which we denote by $R^*(\psi)$. For notational convenience, define δ as

$$\delta := max\left\{0, 1 - \frac{c}{y - 2x}\right\}.$$

Further, for $\psi \geq max\{0,1 - x/[1 + \eta(0)]\}$, define $\hat{R}(\psi)$ as the unique solution to

$$1 - \frac{x[1 - \hat{R}(\psi)]}{1 + \eta\left(\hat{R}(\psi)\right)} = \psi.$$

In words, $\hat{R}(\psi)$ is the maximum amount of risky assets that a firm can invest in, given that regulatory intervention is not triggered in the case where the risky investment fails. It is straightforward to verify that $\hat{R}(\psi)$ strictly increases with ψ, i.e., a more capital-adequate firm is able to bear a larger amount of risks. The following result can then be obtained:

Proposition 1 (Optimal Portfolio Structure) *Suppose that Assumptions 1, 2, and 3 are satisfied. Then the following statements hold:*

i. *If* $\eta(\delta) + \delta x < x - 1$, *then a firm's optimal investment decision is given by*

$$R^*(\psi) = \hat{R}(\psi) \; for \; all \; \psi \in (0, 1).$$

ii. *If* $\eta(\delta) + \delta x \geq x - 1$, *then a firm's optimal investment decision is given by*

$$R^*(\psi) = \begin{cases} 1 & if \; \psi \in \left(0, 1 - \frac{(1-\delta)x}{1+\eta(\delta)}\right], \\ \hat{R}(\psi) & if \; \psi \in \left(1 - \frac{(1-\delta)x}{1+\eta(\delta)}, 1\right). \end{cases}$$

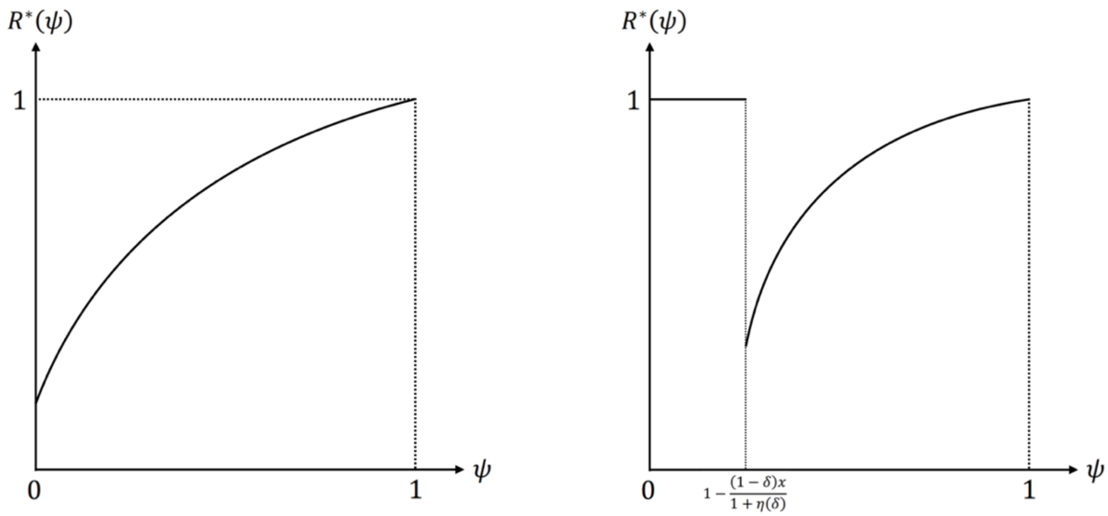
By Proposition 1, the relationship between a firm's optimal portfolio choice R^* and its initial capital adequacy ψ hinges on the comparison between $\eta(\delta) + \delta x$ and $x - 1$. Note that the condition $\eta(\delta) + \delta x < x - 1$ holds when the threshold capital-liability ratio $\eta(\delta)$ is small, i.e., when the capital regulation at δ is loose. In this case, Proposition 1(i) predicts a monotonic relationship between firm's optimal risk-taking R^* and its initial capital-adequacy position ψ. To convey the intuition most clearly, let us consider the case in which the regulatory cost is sufficiently large, i.e., $c \geq y - 2x$.[10] Under a loose capital regulation, no firms will incur a regulatory cost in the good state when the gross return per unit of risky assets is y, regardless of their investment decision R. However, whether firms would be subject to regulatory intervention in the bad state when the return per unit of risky assets is zero, depends on their investment decision. Recall that $\hat{R}(\psi)$ is the maximum amount of risk that a firm can take to avoid

[10] It is noteworthy that Proposition 1 imposes no restrictions on the size of c and holds for $c < y - 2x$.

regulatory intervention when the bad state is realized, and a firm incurs a regulatory cost if and only if $R > \hat{R}(\psi)$. Therefore, the probability of avoiding regulatory intervention is equal to one for $R \leq \hat{R}(\psi)$ and declines to 1/2 for $R > \hat{R}(\psi)$. In other words, all firms face the tradeoff between a higher expected payoff and a higher probability of regulatory intervention when they decide on their holdings of risky assets, indicating that either $R^* = \hat{R}(\psi)$ or $R^* = 1$ in the optimum. With a large regulatory cost in effect (i.e., $c \geq y - 2x$), the firm would opt for $R^* = \hat{R}(\psi)$, which increases with ψ as mentioned previously. As a result, firms with higher initial capital adequacy would invest more in the risky assets, as depicted in Figure 1(a).

When the capital regulation becomes sufficiently stringent (i.e., $\eta(\delta) + \delta x \geq x - 1$), Proposition 1(ii) predicts a U-shaped relationship between firm's optimal risk-taking R^* and its initial capital adequacy position ψ, as depicted in Figure 1(b). Firms with lower capital adequacy would invest in the maximum amount of the risky asset. The degree of the firm's risk-taking drops to a much lower level when its capital position reaches a threshold, i.e., $\psi = 1 - (1-\delta)x/[1+\eta(\delta)]$, and then increases as the firm's capital adequacy further increases.[11] Under a stringent capital regulation, a firm with low capital adequacy (i.e., $\psi < 1 - (1-\delta)x/[1+\eta(\delta)]$) always incurs a regulatory cost in the bad state regardless of its investment decision, and its exposure to regulatory intervention in the good state depends on its investment decision. More risky assets lead to more period-2 capital in the good state and thus a higher capital-liability ratio. This gives the firm incentive to increase its holdings of risky assets. In such a circumstance, increasing investment in the risky asset not only generates a higher expected return to the firm, but also (weakly) reduces the probability that it will face regulatory intervention. As a result, such firms would take the maximum risk. The intuition for the positive relationship between initial capital adequacy and risk-taking among highly capital-adequate firms is reminiscent of that for Proposition 1(i).

[11] The discontinuity of $R^*(\psi)$ illustrated in Figure 1(b) is due to the assumptions that (i) the return of the risky portfolio is binary, and (ii) the regulatory cost is constant. The discontinuity disappears if either assumption is relaxed, in which case a continuous U-shaped curve results. See, for instance, the simulation results in Figure B1(f) in Appendix B3.



(a) $\eta(\delta) + \delta x < x - 1$ (b) $\eta(\delta) + \delta x \geq x - 1$

Figure 1 Firm's Optimal Portfolio Structure

In the insurance sector, the following hypotheses can be derived based on Proposition 1.

H1a There is a positive relationship between an insurer's capital adequacy and its risk-taking behavior.

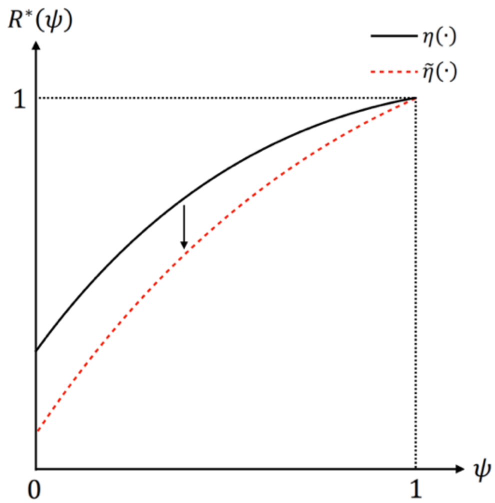
H1b There is a U-shaped relationship between an insurer's capital adequacy and its risk-taking behavior.

Impact of Regulatory Reform Next, we investigate the impact of a regulatory reform on firm's risk-taking behavior based on the characterization of firm's optimal portfolio choice as established in Proposition 1. Recall that a regulatory reform can be captured by a change in the threshold capital-liability ratio $\eta(\cdot)$. Consider two capital regulations $\eta(\cdot)$ and $\tilde{\eta}(\cdot)$. We say that a firm is subject to a higher (respectively, lower) regulatory pressure under $\tilde{\eta}(\cdot)$ than under $\eta(\cdot)$ if $\tilde{\eta}(R) > \eta(R)$ (respectively, $\tilde{\eta}(R) < \eta(R)$) for all $R \in [0,1]$. We then obtain the following comparative statics with respect to the threshold capital-liability ratio $\eta(\cdot)$.

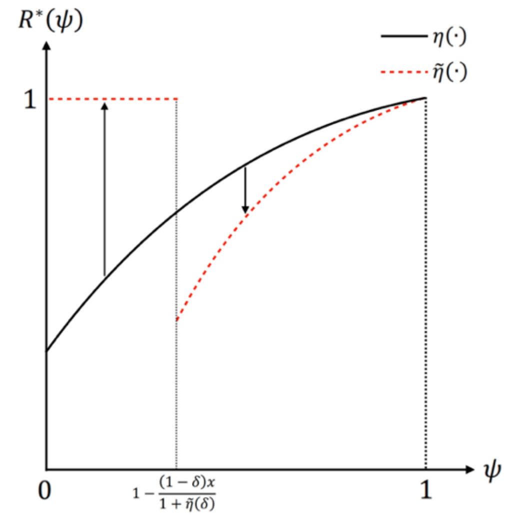
Proposition 2 (Impact of Regulatory Reform on Risk-taking) *Suppose that Assumptions 1, 2, and 3 are satisfied, and consider a regulatory reform from $\eta(\cdot)$ to $\tilde{\eta}(\cdot)$, whereby firms are subject to a higher regulatory pressure under $\tilde{\eta}(\cdot)$. Then the following statements hold:*

- *i.* *If $\tilde{\eta}(\delta) + \delta x < x - 1$, then all firms strictly decrease their holdings of the risky asset.*
- *ii.* *If $\tilde{\eta}(\delta) + \delta x \geq x - 1$, then*
  - *a)* *Firms with initial capital adequacy $\psi \in \left(0, 1 - \frac{(1-\delta)x}{1+\tilde{\eta}(\delta)}\right]$ weakly increase their holdings of the risky asset;*
  - *b)* *Firms with initial capital adequacy $\psi \in \left(1 - \frac{(1-\delta)x}{1+\tilde{\eta}(\delta)}, 1\right)$ strictly decrease their holdings of the risky asset.*

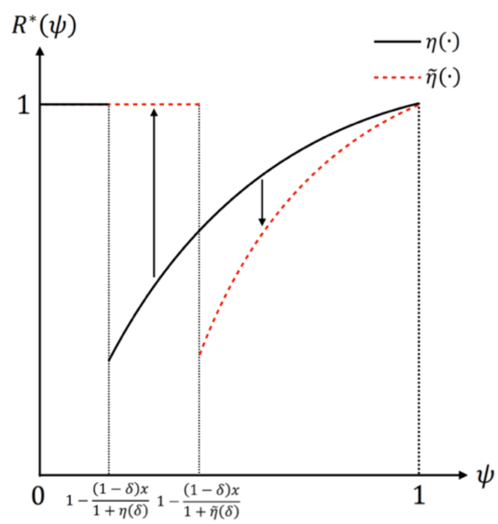
For ease of exposition, we consider the case in which the original regulation $\eta(\cdot)$ satisfies $\eta(\delta) + \delta x < x - 1$, that is, the case where a firm's optimal risk-taking behavior strictly increases with its capital as depicted in Figure 1(a). The results are illustrated in Figures 2(a) and 2(b). In this case, all firms are only concerned with the capital-liability ratio in the bad state when they make their investment decision under the original regulation policy. If $\tilde{\eta}(\delta) + \delta x < x - 1$, these concerns remain qualitatively the same except that the threshold ratio $\tilde{\eta}(R)$ becomes more difficult to satisfy than the ante-reform threshold ratio $\eta(\delta)$. In response, all firms reduce their risk-taking as illustrated in Figure 2(a).



(a) $\eta(\delta) + \delta x < \tilde{\eta}(\delta) + \delta x < x - 1$



(b) $\eta(\delta) + \delta x < x - 1 \leq \tilde{\eta}(\delta) + \delta x$



(c) $x - 1 \leq \eta(\delta) + \delta x < \tilde{\eta}(\delta) + \delta x$

Figure 2 Impact of a Regulatory Reform on Firm's Optimal Risk-taking Behavior

Interestingly, when $\tilde{\eta}(\delta) + \delta x \geq x - 1$, Proposition 2(ii) predicts the existence of a threshold of initial capital adequacy, below which firm's risk-taking may increase. In this case, a regulatory reform that intends to restrain firm's risk-taking by increasing regulatory pressure may backfire when the capital regulation becomes too stringent. Specifically, the incentive of firms with low capital adequacy (i.e., $\psi < 1 - (1 - \delta)x/[1 + \tilde{\eta}(\delta)]$) would be fundamentally reshaped by the reform. Prior to the reform, all firms would be concerned only with the capital-liability ratio in the bad state when deciding on their asset composition, and the optimal investment strategy would balance the tradeoff between a higher expected return and a higher probability of regulatory intervention. However, this tradeoff fades away for firms with low capital adequacy when the regulator employs an overly stringent capital regulation policy. The bad state becomes irrelevant to these firms after the reform as they always fail to meet the higher requirement; and they turn their concern to the impact of the investment decision on the capital-liability ratio in the good state. As Figure 2(b) predicts, these firms would invest in the risky asset in a very aggressive manner, instead of holding a positive amount of the safe asset. The analyses for the case $\eta(\delta) + \delta x \geq x - 1$ are similar, and the result is illustrated in Figure 2(c).

Proposition 2 has the following implications in the insurance sector.

H2a (Regulatory intention) Higher capital requirements reduce risk-taking of all insurers.

H2b (Counter-regulatory intention) Higher capital requirements induce risk-taking among insurers below a certain solvency-ratio threshold, and reduce risk-taking among insurers above the threshold.

3.3 Model Extensions

Before we proceed to our empirical analysis, we show that the main results derived in Propositions 1 and 2 are robust to several different specifications.

Bankruptcy Costs When a firm goes bankrupt, the value of the firm's liabilities exceeds its assets, or equivalently, $K < 0$. The firm may then have to liquidate its assets and incur a cost C that is greater than the regulatory intervention cost c. Note that the baseline model in Section 3.1 corresponds to $C = c$. In Appendix B2, we consider the case where $C > c$ and show that our main results in Propositions 1 and 2 apply, once we replace $\delta \coloneqq max\{0, 1 - c/(y - 2x)\}$ with $\delta' \coloneqq max\{0, 1 - C/(y - 2x)\}$, given that the difference between C and c is not excessively large, i.e., $C - c < (y - 2x)\,(1 - \delta)/[1 + \eta(\delta)]$.[12]

Non-constant Regulatory Costs Another assumption made in the baseline model is that the

[12] When the difference between C and c is sufficiently large, bankruptcy concern becomes the primary determinant of firms' risk-taking behavior. This scenario is beyond the scope of our paper.

regulatory cost is constant, once a firm's capital adequacy ratio or solvency ratio is below the trigger threshold for regulatory actions. This assumption is consistent with the Chinese solvency regulation. In some markets, firms with a capital-adequacy ratio or a solvency ratio far below the threshold may incur a higher regulatory cost than those whose capital-adequacy ratio or solvency ratio is slightly below the threshold. Next, we generalize the model to allow for non-constant regulatory costs. More formally, we assume that a firm is subject to a regulatory cost that amounts to $c + \sigma[\tau - K/f(A, L, R)]$, with $\sigma \geq 0$, if its capital-adequacy ratio or solvency ratio falls below τ. The model degenerates to the baseline when $\sigma = 0$.

Intuitively, Proposition 1(i) remains unchanged with a positive σ because regulatory intervention is not triggered in the second period under firms' optimal portfolio choice when the regulation is loose (see Figures B1(a)-B1(c) in Appendix B3). In other words, σ does not enter firms' expected payoff in the optimum. However, when the regulation is strict, a large σ may alter the firms' risk-taking incentive. To see this, consider the capital-inadequate firms who choose $R^* = 1$ as predicted in Proposition 1(ii) (see also Figure 1(b)). Recall that these firms always incur a regulatory cost in the bad state. Because the regulatory cost is constant in the baseline model (i.e., $\sigma = 0$), these firms would only concern themselves with the good state and would take the maximum risk. When σ is sufficiently large, taking the maximum risk can be suboptimal to firms because doing so would produce a very low capital-adequacy ratio or solvency ratio in the bad state and thus would cause a large regulatory cost. As a result, these firms choose $R^* < 1$ rather than $R^* = 1$ in the optimum. Figures B1(d)-B1(f) in Appendix B3 confirm this intuition. They again depict a U-shaped relationship between a firm's capital adequacy and its risk-taking behavior. In addition, Figures B2(a)-B2(d) in Appendix B3 suggest that Proposition 2 remains qualitatively unchanged when σ is positive.

Risk-taking on the Liability Side We assume in the baseline model that uncertainty in a firm's payoff stems entirely from the asset investment and that the return on the liability portfolio is deterministic and normalized to zero. As stated previously, an insurer may adjust its insurance portfolio between a risky product line and a safe product line on the liability side. In Appendix B1, we show that our model can be adapted to the situation where firms make risk-taking decisions on the liability side.

Allowing risk-taking on both asset and liability sides requires an insurer's minimum capital requirement $f(\cdot)$ depend on the firm's risk-taking behavior on the assets side---which we denote by R_A---and that on the liability side, which we denote by R_L. In this extended setting, firms make two risk-taking decisions rather than one and can take advantage of risk diversification between its asset and liability portfolios.

Consider a solvency regulation with required capital $f(A, L, R_A, R_L)$ such that for all $R \in (0,1]$, there exists some $\mu \in (0,1)$ such that $\min\{f(A, L, 0, R), f(A, L, R, 0)\} > f(A, L, \mu R, (1-\mu)R)$. Such an extension is innocuous for the predictions for capital regulation given that firms' risk diversification benefits between asset and liability portfolios are not excessively large.

In Section 5.3, we provide empirical results for the product risk-taking and the aggregate portfolio risk-taking considering risk diversification between asset and product portfolios. The results are consistent with the above theoretical predictions.

4. Data and Empirical Strategy

In this section, we describe the data, the process of variable construction, and the empirical design we use to test the hypotheses.

4.1 Data and Sample

We collect our data from three main sources. The primary source is the solvency regulatory reports of all nonlife and life insurers that operated in China between 2012 and 2017. These reports were based on Chinese Solvency I between 2012 and 2015 and on C-ROSS between 2015 and 2017. As mentioned in the Introduction, each insurer provided two solvency reports in 2015, one under Chinese Solvency I and one under C-ROSS. We complement the missing values and some income statement variables based on the Year Books of China's Insurance (2013-2018). Where missing values remained, we requested information from the regulator. The consolidated dataset contains the corporate financial information from regulatory balance sheets and income statements.

Our sample includes all nonlife and life insurers that operated in the Chinese market at the end of 2012. We exclude Lloyd's China because it ceded all written premiums to its overseas parent company, which yields an infinite solvency ratio under Chinese Solvency I in 2015 (Lloyd's China, 2016). We also exclude China Life Group because it only ran off the high-guarantee-return legacy portfolio of China Life written before 1999. In this sense, our sample covers the entire population of insurers in the Chinese insurance market. It includes 62 nonlife insurers and 66 life insurers.[13] As the third-largest insurance market in the world, the premiums represented by our sample were approximately USD 230 billion in 2012 and USD 530 billion in 2017. The Chinese insurance market is moderately concentrated with three largest

[13] Two nonlife and four life insurers changed their major shareholders during the sample period, indicated by company name changes. Their risk-taking behavior changes might have been influenced by business strategy adjustments related to the shareholder changes. Our results are robust if we exclude these insurers.

insurers taking over 60% market shares.[14] However, the market is very competitive. About one-third insurers in the Chinese market are foreign-owned international players.

We construct the panel sample using the information from 2013 to 2017. The 2012 information is used to construct the changes from 2012 to 2013 and for the one-period lag instruments of some variables. The panel includes 301 nonlife and 303 life firm-year observations. It is slightly unbalanced due to remaining missing values for some variables after the exploration of all three data sources.

4.2 Variables

Capital Shock In 2015, the pilot implementation year of C-ROSS, we have two observations for each insurer. One observation is based on the in-effect Chinese Solvency I and the other on the for-information-only C-ROSS. This feature of our sample generates an insurer-specific measure of capital shock for all insurers in the market, defined as

$$CapitalShock_i = SolvencyRatio_{i,2015,C-ROSS} - SolvencyRatio_{i,2015,ChineseSolvencyI}.$$

CapitalShock$_i$ captures the change of regulatory pressure driven by the solvency regulatory reform on insurer *i.*[15] The key identifying assumption here is that a given solvency ratio represents the same level of regulatory pressure under both solvency systems. This assumption is realistic because the triggers for regulatory intervention (i.e., solvency ratio <100%) and regulatory attention (i.e., solvency ratio <150%) did not change before or after the reform and because solvency ratios under both solvency systems result from the same portfolio for each insurer in 2015. Clearly, the regulatory pressure on an insurer *i* increases due to the reform if *CapitalShock$_i$* is negative and decreases if *CapitalShock$_i$* is positive. Alternatively, in a robustness test in Section 5.3, we measure the capital shock in percentage defined as follows.

$$CapitalShock_i(\%) = \frac{SolvencyRatio_{i,2015,C-ROSS}}{SolvencyRatio_{i,2015,ChineseSolvencyI}} - 1$$

The percentage capital shock measure addresses the concern that the same degree of drop in solvency ratio indicates a higher pressure for insurers with low solvency ratios than for those with high solvency

[14] Barth et al. (2004) document the adverse impact of capital regulation on bank risk-taking based on samples from 107 countries, which includes the Chinese market. Their results suggest that the adverse impact is independent of the market structure (i.e., market concentration or number of market players) and the market maturity.

[15] Solvency ratio may capture more than just the degree of regulatory pressure. It may also sometimes reflect pressure from rating agencies, institutional investors, and/or policyholders, who use the solvency ratio and/or the relative position of an insurer's solvency ratio to its peers to make investment or insurance purchase decisions. The construction of our *CapitalShock* measure ensures that the identified pressure change for each insurer is purely regulation-driven. It filters out market-driven pressure changes on insurers.

ratios.

Risk Measures We measure the risk change of an insurer by the differences between its risk-taking measures in two adjacent years, defined as

$$\Delta Risk_{i,t} = Risk_{i,t} - Risk_{i,t-1}.$$

We follow Baranoff et al. (2007) and Eling and Marek (2014) to quantify an insurer's asset risk-taking by the opportunity asset risk (*OAR*) measure. The *OAR* measure aggregates the asset portfolio structure and the volatility of the opportunity cost of the asset portfolio. The latter is captured by the volatility of returns if certain asset classes were invested in the representative indices. Specifically, we consider 11 asset classes for each insurer: cash and deposit, government bonds, financial bonds, corporate bonds, securities, trusts, asset management accounts, infrastructure, real estate, derivatives, and others. The corresponding indices for the Chinese market are obtained from CSINDEX, the database of China Securities Index Co. Ltd. We first estimate the monthly return rate based on each insurer's asset structure, assuming that the assets were invested in indices of the respective asset classes. We then calculate the standard deviation of the monthly return rate in each year for each insurer, and take the natural logarithm of it to obtain the following *OAR* measure:

$$OAR_{i,t} = \ln\left(Std_m \frac{\sum_{a=1}^{11} Asset_{i,t,a} \times Return_{a,m}}{TotalInvestedAsset_{i,t} + Cash_{i,t}}\right).$$

As robustness checks (see Section 5.3), we use two alternative asset risk measures: regulatory asset risk (*RAR*, Baranoff et al., 2007) and the share of equity and alternative investments (*RiskyAssetShare,* Gaver and Pottier, 2005). Consistent with our theoretical modeling, our empirical analyses focus on the asset risk. Analyzing the asset risk is also driven by the fact that the Chinese solvency regulatory reform mainly updated the rules concerning the capital charges for asset risks and had a relatively milder impact on the product risk (Liu et al., 2019).

We follow Cummins and Sommer (1996) and Shim (2010) to measure the aggregate portfolio risk of an insurer by the volatility of asset to liability ratio (*VAL*) as follows.

$$VAL_{i,t} = \sqrt{\sigma_{A\,i,t}^2 + \sigma_{L\,i,t}^2 - 2\rho_i \sigma_{A\,i,t} \sigma_{L\,i,t}}\,,$$

where $\sigma_{A\,i,t} = \frac{\sum_{a=1}^{11} Asset_{i,t,a}}{TotalInvestedAsset_{i,t} + Cash_{i,t}} \times Std_t ln \frac{Index_{t,a}}{Index_{t-1,a}}$, $\sigma_{L\,i,t} = \frac{\sum_{l=1}^{17} Loss_{i,t,l}}{TotalLoss_{i,t}} \times Std_t ln \frac{Loss_{i,t,l}}{Loss_{i,t-1,l}}$, and ρ_i is the correlation between $\sigma_{A\,i,t}$ and $\sigma_{L\,i,t}$. The *VAL* measure incorporates information about the composition of the asset and liability portfolios and accounts for diversifications and correlations between assets and liabilities. It is important to take the liability portfolio of insurance operation into account because the product underwriting risk is a major determinant of insurers' portfolio risk (Shim, 2010).

Thresholds As our theoretical model predicts, the impact of a capital shock on firm risk-taking depends on the firm's capital-adequacy position and may reverse at a certain threshold of capital adequacy. We thus define *Threshold(interval)*$_i$ as a dummy variable which equals one if an insurer's solvency ratio falls in a certain *interval* of *SolvencyRatio*. The impact of *CapitalShock* may vary in direction and magnitude across different *SolvencyRatio* intervals.

We obtain the cutoff points of *Threshold(interval)*$_i$ based on both the regulatory rules and the threshold regressions. According to Chinese Solvency I and C-ROSS, insurers with a solvency ratio equal to or greater than 100% are solvent, and those with a ratio below 100% are subject to regulatory intervention. The Chinese regulation further distinguishes solvent insurers into two categories. Insurers with a solvency ratio between 100% and 150% require "regulatory attention" and the regulator may impose additional regulatory pressure on the insurer by taking "soft measures" such as "regulatory talks" to urge the insurer to increase its solvency ratio. A solvency ratio between 100% and 150% is like a yellow light to the insurer, and a solvency ratio above 150% is like a green light. Therefore, 150% is a natural regulation-based candidate for the threshold that captures the critical capital adequacy cutoff, $1-(1-\delta)x/[1+\tilde{\eta}(\delta)]$, as predicted in Proposition 2(ii).

Alternatively, we follow Hansen (1999) and Lin et al. (2014) to estimate the *Threshold(interval)*$_i$ based on our empirical samples. We conduct the threshold regression below for nonlife and life insurers separately. The estimation is based on the post-reform sample in 2016 and 2017 after C-ROSS became effective and when *CapitalShock* could possibly produce an effect.

$$\Delta Risk_{i,t} = \beta_0 + \beta_1 CapitalShock_i + \beta_2 SolvencyRatio_{i,t-1} + \beta_3 X_{i,t} + \varepsilon_{i,t} \qquad (1)$$

The coefficients of *CapitalShock* β_1 and the constant β_0 are allowed to vary across estimated intervals of *SolvencyRatio.* We use *SolvencyRatio* at *t-1,* i.e., the end of previous year, to capture the initial capital-adequacy position ψ in our theoretical model (see Table 1 in Section 3), which also minimizes the concern about endogeneity. *SolvencyRatio* and the estimate of *Threshold(interval)*$_i$ are based on C-ROSS. This is consistent with the theoretical cutoff in Proposition 2, which depends on the post-reform regulation $\tilde{\eta}(\delta)$. We allow the threshold regression to optimally choose the number of thresholds according to the Akaike information criterion (AIC). The threshold regressions produce one threshold for nonlife insurers and two thresholds for life insurers. As previously mentioned, we focus on the asset risk-taking analyses in our baseline analyses. The estimated thresholds from asset risk regressions are 285.5% for nonlife and 135.2% and 274.2% for life insurers (see Appendix C1).[16] The estimated thresholds indicate that insurers consider not only their distance from the regulatory-intervention trigger but also their solvency positions relative to peers when making risk-taking decisions. Thus, in a robustness test (see Section 5.3), we use terciles as the thresholds for nonlife and life insurers, respectively.

4.3 Summary Statistics

Table 2 presents the summary statistics of all variables in our nonlife and life samples. The samples capture the diversity in firm size, profitability, asset mix, capital ratio, and ownership (domestic vs. foreign). The samples cover large, medium, small, and start-up insurers. About one third of insurers received a positive *CapitalShock*, i.e., their *SolvencyRatio* under C-ROSS was higher than that under Chinese Solvency I in 2015, indicating a decrease in regulatory pressure. The other two thirds suffered a negative *CapitalShock* and their regulatory pressure increased due to the reform. To address the concern on outliers, we censor the largest and smallest *CapitalShock* in nonlife and life samples, respectively, in a robustness test. The results remain intact (see Section 5.3).

The *SolvencyRatio* ranges from 100% to 6,590% for nonlife insurers and from 75% to 8,980% for life insurers. The median *SolvencyRatio* values for nonlife and life insurers are 290% and 237%, respectively. The average *SolvencyRatio* for nonlife insurers (601%) is much higher than that for life insurers (357%) because some foreign-owned nonlife insurers kept very high solvency ratios for future business development, while the Chinese market did not open for foreign-owned life insurers (only joint ventures) during the sample period. Another explanation is that life business is usually larger and less volatile, and thus the costs of keeping redundant capital are higher.

$SolvencyI_t$ is a dummy variable, and equals 1 if the Chinese Solvency I is the effective regulation in year t. That is, $SolvencyI_t$ =1 if t=2013, 2014, 2015, and $SolvencyI_t$ =0 if t=2016, 2017. Our sample includes a set of firm-specific control variables ($X_{i,t}$): Size ($lnTotalAsset_{i,t-1}$), profitability ($ROA_{i,t}$), $AssetGrowth_{i,t}$ from $t-1$ to t, asset mix ($AssetHHI_{i,t}$), firm affiliation ($Group_i$ equals 1 if the insurer is affiliated with an insurance or financial group), and ownership ($Domestic_i$ equals 1 if the insurer is Chinese and 0 if it is a foreign insurer according to the regulatory definition). We also use two macroeconomic environmental control variables (M_t): $GDPGrowth_t$ from $t-1$ to t, and $IndustryGrowth_t$ from $t-1$ to t (nonlife or life premium

[16] The cutoff *SolvencyRatio* of inflection is larger in the nonlife sample (285.5%) than in the life sample (135.2%). However, they are very close in terms of distance to the mean *SolvencyRatio* in the respective industries. 285.5% is 0.37 standard deviations below the mean *SolvencyRatio* (601%) in the nonlife industry, and 135.2% is 0.35 standard deviations below the mean *SolvencyRatio* (357%) in the life industry.

growth). When we discuss the policy implications in Section 6, we also introduce the score of qualitative risk assessment $SARMRA_{i,t}$ for each insurer in 2016 and 2017 according to C-ROSS.

Table 2 Summary Statistics

	Mean	S.D.	Min.	PCTL.10	Median	PCTL.90	Max.
Panel A: Nonlife sample (2013-2017)	***No. of insurers=62, Firm-year observations=301***						
CapitalShock	-4.79	10.3	-61.7	-14.3	-0.71	0.88	1.34
OAR (AssetRisk)	0.18	0.85	-1.81	-1.03	0.23	1.29	1.84
ΔOAR (ΔAssetRisk)	0.078	0.72	-1.70	-0.96	0.090	1.02	2.14
ΔVAL	0.011	0.20	-1.84	-0.11	0.0074	0.12	1.62
Threshold (>=285.5%)	0.51	0.50	0	0	1	1	1
Threshold (>=150.0%)	0.96	0.20	0	1	1	1	1
SolvencyRatio	6.01	8.63	1.00	1.68	2.90	15.0	65.9
CapitalRatio	0.36	0.16	0.053	0.19	0.33	0.59	0.86
TotalAsset (million CNY)	29,889	83,060	241	840	3,641	69,282	555,367
ROA	-0.0010	0.053	-0.26	-0.061	0.0079	0.043	0.30
AssetGrowth	0.23	0.60	-0.51	-0.024	0.12	0.45	5.49
AssetHHI	0.50	0.29	0.14	0.21	0.39	1	1
SolvencyI	0.59	0.49	0	0	1	1	1
Group	0.18	0.38	0	0	0	1	1
Domestic	0.66	0.48	0	0	1	1	1
GDPGrowth	0.071	0.0039	0.067	0.067	0.069	0.078	0.078
IndustryGrowth	0.14	0.027	0.10	0.10	0.14	0.17	0.17
SARMRA[a]	73.1	7.66	23.6	63.9	74.3	80.2	85.0
Panel B: Life sample (2013-2017)	***No. of insurers=66, Firm-year observations=303***						
CapitalShock	-1.52	4.24	-31.7	-4.32	-0.40	0.86	3.03
OAR (AssetRisk)	0.66	0.70	-1.13	-0.29	0.71	1.54	2.09
ΔOAR (ΔAssetRisk)	0.074	0.73	-1.77	-1.05	0.13	0.88	1.83
ΔVAL	0.048	0.53	-2.04	-0.34	-0.0038	0.41	3.15
Threshold[135.2%, 274.2%)	0.54	0.50	0	0	1	1	1
Threshold (>=274.2%)	0.35	0.48	0	0	0	1	1
Threshold (>=150.0%)	0.88	0.33	0	0	1	1	1
SolvencyRatio	3.57	6.42	0.75	1.34	2.37	5.92	89.8
CapitalRatio	0.15	0.11	0.015	0.054	0.12	0.29	0.75
TotalAsset (million CNY)	118,904	267,191	252	3,107	27,840	357,560	2,220,986
ROA	-0.0035	0.035	-0.22	-0.030	0.0039	0.019	0.11
AssetGrowth	0.43	0.75	-0.43	-0.0081	0.20	0.98	5.97
AssetHHI	0.29	0.12	0.12	0.18	0.26	0.41	1.00
SolvencyI	0.58	0.49	0	0	1	1	1
Group	0.23	0.42	0	0	0	1	1
Domestic	0.58	0.49	0	0	1	1	1
GDPGrowth	0.071	0.0038	0.067	0.067	0.069	0.078	0.078
IndustryGrowth	0.22	0.093	0.079	0.079	0.20	0.37	0.37
SARMRA[a]	77.4	6.58	34.7	70.7	78.5	83.0	86.1

Notes: a. The qualitative risk assessment scores (SARMRA) are only reported under C-ROSS in 2016-2017 with 124 nonlife firm-year observations and 126 life firm-year observations.

4.4 Empirical Strategy

To examine the relationship between an insurer's capital adequacy and its risk-taking behavior (H1), we follow the existing literature and estimate the partial adjustment model as shown in Equation (2) below (Shim, 2010; Cheng and Weiss, 2013; Lin et al., 2014). The lagged risk measure is included in the equation to control for the static part of a firm's risk-taking behavior. The coefficients of *CapitalAdequacy* β_2 and its square β_3 capture the dynamics of firm risk-taking that are affected by the firm's initial capital-adequacy position. Note that the threshold regression approach is not necessary and does not apply when analyzing the relationship between capital adequacy and firm risk-taking (H1) because the threshold variable and the determinant are the same *CapitalAdequacy*, and the nonlinear impact of *CapitalAdequacy*, if any, has been captured by its quadratic term.

$$Risk_{i,t} = \beta_0 + \beta_1 Risk_{i,t-1} + \beta_2 CapitalAdequacy_{i,t-1} + \beta_3 CapitalAdequacy_{i,t-1}^2 + \beta_4 SolvencyI_t + \beta_5 X_{i,t} + \beta_6 M_t + \varepsilon_{i,t} \quad (2)$$

We measure the capital adequacy of an insurer by (i) the non-risk-based *CapitalRatio* (capital-to-asset ratio) and (ii) the *SolvencyRatio* under effective solvency regulation. Both measures are commonly used in the literature (e.g., Shim, 2010; Cheng and Weiss, 2013; Lin et al., 2014). We use *CapitalAdequacy* at *t-1,* i.e., the end of previous year, to capture the initial capital-adequacy position ψ in our theoretical model (see Table 1 in Section 3), which also minimizes the concern about endogeneity. The quadratic term of *CapitalAdequacy* is included to account for the hypothesized non-linear relationship in H1b. *CapitalRatio* and *SolvencyRatio* are centered to avoid multicollinearity. $SolvencyI_t$ controls for the effective solvency regulation during the sample period. $X_{i,t}$ and M_t are sets of firm-specific and year-specific control variables, respectively, as summarized in Table 2. The variance inflation factors are all below 5, suggesting that multicollinearity is not a problem.

We use the dynamic panel Arellano-Bond system GMM approach to estimate the partial adjustment model in Equation (2) for life and nonlife insurers, respectively. $ROA_{i,t}$, $AssetGrowth_{i,t}$, and $AssetHHI_{i,t}$ are considered to be endogenous variables, and their lags and all exogenous variables are used as instruments. $CapitalAdequacy_{i,t-1}$, $lnTotalAsset_{i,t-1}$, $Group_i$, $Domestic_i$, $GDPGrowth_t$, and $IndustryGrowth_t$ are considered to be exogenous variables. To account for the small number of insurers, we estimate Windmeijer's (2005) WC-robust standard errors, which offer a finite sample correction for the dynamic panel system GMM estimators.

To analyze the impact of a capital shock on insurers' risk-taking behavior (H2), we estimate Equation (3) below.

$$\Delta Risk_{i,t} = \beta_0 + \beta_1 CapitalShock_i + \beta_2 Threshold_i + \beta_3 SolvencyI_t + \beta_4 CapitalShock_i \times Threshold_i + \beta_5 SolvencyI_t \times CapitalShock_i + \beta_6 SolvencyI_t \times Threshold_i + \beta_7 SolvencyI_t \times CapitalShock_i \times Threshold_i + \beta_8 SolvencyRatio_{i,t-1} + \beta_9 X_{i,t} + \beta_{10} M_t + \varepsilon_{i,t} \quad (3)$$

We include the interaction terms between $SolvencyI_t$, $CapitalShock_i$, and $Threshold_i$ (and among all three of them) in Equation (3). This practice allows *CapitalShock* to have differential impacts across intervals of *SolvencyRatio*, to have an impact in the post-reform period, and to have no impact in the ante-reform period. We introduce the interaction terms step by step. We control for the initial capital-adequacy position of an insurer by its $SolvencyRatio_{i,t-1}$. $X_{i,t}$ and M_t are the same as in Equation (2).

We estimate Equation (3) using the random-effects panel regressions, as well as the random-effects model with instruments (Baltagi, 2013), in which we consider $ROA_{i,t}$, $AssetGrowth_{i,t}$, and $AssetHHI_{i,t}$ to be endogenous variables and use their one-year lag and all exogenous variables as the instruments. We use fixed-effects model as a robustness test because our variable of interest $CapitalShock_i$ does not vary over years and thus the results of fixed-effects models only provide indirect evidence (see Section 5.3). The variance inflation factors are all below 5, indicating that multicollinearity is not a concern. The standard errors are clustered at the firm level to further account for uncontrollable heterogeneity between insurers. To account for the small sample size, we use t-statistics for statistical inferences in the IV models, which are more conservative than the commonly used Z-statistics in random-effects models. We also use the bootstrapped standard errors as a robustness test to address the small sample concern, and our conclusions remain intact (see Section 5.3).

5. Empirical Results

5.1 The Relationship between Capital Adequacy and Firm Risk-taking (H1)

Table 3 reports the estimated results of Equation (2). The coefficients of $SolvencyRatio_{t-1}$ and $CapitalRatio_{t-1}$ are significantly positive in both the nonlife and life samples. The coefficients of $SolvencyRatio_{t-1}^2$ are negative and those of $CapitalRatio_{t-1}^2$ are insignificant.[17] The results suggest that there exists a positive relationship between capital adequacy and an insurer's asset risk-taking, and this positive relationship becomes weaker as the insurer's *SolvencyRatio* increases. These results are

[17] We note the different impacts of solvency ratio and capital ratio. The impact of solvency ratio on insurer risk-taking weakens as the solvency ratio increases. This suggests that the solvency ratio becomes less relevant when it is far above the regulatory intervention trigger. However, the capital ratio is always relevant, probably because the insurer needs to take more risks for more profits as returns to the capital invested.

consistent with H1a and Figure 1(a). The results do not support H1b as we do not identify high risk-taking insurers with very low capital adequacy as depicted in Figure 1(b). This is probably because we have very few insurers that are severely under-capitalized. Our results are consistent with those in Cummins and Sommer (1996), Baranoff and Sager (2002), Cheng and Weiss (2013), and Chen et al. (2019) in the sense that we document a generally positive relationship between capital adequacy and insurer risk-taking. Our result is also consistent with Shim (2010) and Mankaï and Belgacem (2016). They find that the correlation between capital and risk are stronger for insurers with low RBC ratios and weaker for insurers with high RBC ratios.

We note that the coefficients of *SolvencyI* are significantly positive in all specifications, suggesting that the Chinese solvency regulatory reform on average reduces the asset risk of insurers. This is in line with the regulatory intention. The coefficients of OAR_{t-1} are positively related to the dependent variable OAR_t, indicating that the asset risk of an insurer is partially determined by its asset risk structure in the previous period. The results justify the use of partial adjustment models and the dynamic panel estimation approach.

Table 3 H1 Results (Dependent Variable: *OAR*; Sample Period: 2013-2017)

	(1)	(2)	(3)	(4)
Samples	**Nonlife**		**Life**	
$SolvencyRatio_{t-1}$	0.00695*		0.0150***	
	(0.00419)		(0.00557)	
$SolvencyRatio_{t-1}^2$	-0.000306***		-0.000446**	
	(9.05e-05)		(0.000226)	
$CapitalRatio_{t-1}$		0.620*		0.984*
		(0.372)		(0.599)
$CapitalRatio_{t-1}^2$		0.411		-0.777
		(1.743)		(1.380)
SolvencyI	0.815***	0.916***	0.869***	0.897***
	(0.117)	(0.115)	(0.177)	(0.137)
OAR_{t-1}	0.428***	0.458***	0.267**	0.252*
	(0.0756)	(0.0668)	(0.107)	(0.133)
$lnTotalAsset_{t-1}$	-0.147	-0.0935	-0.0563	-0.0930
	(0.209)	(0.172)	(0.112)	(0.132)
ROA	1.721*	1.445	2.202	0.730
	(0.927)	(1.087)	(3.642)	(3.755)
AssetGrowth	0.0367	0.0342	-0.0304	-0.0340
	(0.0595)	(0.0608)	(0.100)	(0.113)
AssetHHI	-1.443**	-1.388***	0.362	0.131
	(0.619)	(0.499)	(0.915)	(1.102)
Group	-0.0239	-0.178	-0.937	-0.611
	(1.112)	(0.828)	(0.609)	(0.674)
Domestic	0.432	0.241	-0.306	-0.0285
	(0.506)	(0.315)	(0.467)	(0.409)
GDPGrowth	70.99***	75.86***	15.74	15.09
	(24.31)	(24.84)	(21.60)	(33.96)
IndustryGrowth	-15.59***	-16.21***	4.868***	4.664***
	(2.548)	(2.571)	(0.670)	(0.904)
Observations	301	301	303	303
No. of insurers	62	62	66	66
Wald X^2	485.30	456.82	303.85	921.91

Notes: We report the estimated coefficients of the dynamic panel Arellano-Bond system GMM regressions and the Windmeijer's (2005) WC-robust standard errors, correcting for small sample size, in parentheses. *, **, and *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. Constants are included but not reported.

5.2 The Impact of Capital Shock on Firm Risk-taking (H2)

Table 4 reports the estimated results of Equation (3). Columns 1-6 (7-12) are based on the nonlife (life) insurer sample. We present both the coefficients of random-effects models and the EC-2SLS estimators of the random-effects IV models (Baltagi, 2013). Columns 1-2 and 7-8 do not allow for differential *CapitalShock* impacts at different *SovlencyRatio* intervals (i.e., do not allow for any threshold effects). Columns 3-4 and 9-10 are based on the regression-estimated thresholds. Columns 5-6 and 11-12 are based on the regulatory attention thresholds. The coefficients of *SolvencyI* are significantly positive in all specifications, again showing that the Chinese solvency regulatory reform has an overall reduction effect on asset risk.

The coefficients of *CapitalShock* capture the impact of regulatory pressure shock on firm risk-taking during the post-reform period in 2016 and 2017. The interaction term of *SolvencyI × CapitalShock* teases out the impact of *CapitalShock* in the ante-reform period, which is assumed to be random because *CapitalShock* only became known to the insurer by the end of 2015. The coefficients of *CapitalShock* in Columns 1-2 and 7-8 are insignificant, suggesting that there is no single-direction impact of *CapitalShock* on insurer risk-taking.

In the nonlife insurance results, the coefficients of *CapitalShock* are significantly negative in Columns 3-6 (-0.0119***, -0.00838**, -0.0453***, -0.0353**), suggesting that the impact of an increase (decrease) in regulatory pressure is associated with more (less) asset risk-taking for low-solvency insurers. This result holds under both the regression-estimated threshold of 285.5% (Columns 3-4) and the regulatory-attention threshold of 150% (Column 5-6). The significantly positive interaction terms between *CapitalShock* and *Threshold* suggest that the impact of *CapitalShock* on nonlife insurers above the threshold significantly differs from its impact on those below it. The additional results in Appendix C2 show that the impact of *CapitalShock* becomes significantly positive above the 285.5% threshold and insignificant above the 150% threshold. The latter insignificance is mainly due to the mix of the positive and negative impacts in the *SolvencyRatio* interval over 150%.

The results are similar in the life insurance sample. The impact of *CapitalShock* is significantly negative for life insurers with a solvency ratio below the first estimated threshold of 135.2% (-0.109**, -0.103** in Columns 9-10) or below the regulatory attention threshold of 150% (-0.104**, -0.0982* in Columns 11-12). For life insurers with solvency ratios that lie between the first and the second estimated thresholds (i.e., with solvency ratios between 135.2% and 274.2%), the impact of *CapitalShock* significantly differs from its impact on those below these levels, as suggested by the significantly positive interaction terms between *CapitalShock* and *Threshold[135.2%, 274.2%)* in Columns 9-10. The additional results in Appendix C2 show that the impact of *CapitalShock* between the two estimated thresholds becomes significantly positive. For life insurers above the second estimated threshold (i.e., *SolvencyRatio*>274.2%), the impact of *CapitalShock* remains negative as the interaction term *CapitalShock×Threshold (≥274.2%)* is insignificant.[18] For life insurers above the regulatory threshold of 150%, the aggregate impact of *CapitalShock* is insignificant because the positive-impact interval is pooled together with the negative-impact interval.

In addition, we repeat our analyses in two subsamples, depending on *CapitalShock* relative to zero, i.e., insurers with increased regulatory pressure (*CapitalShock<0*) and those with decreased regulatory pressure (*CapitalShock>0*). No insurer has a zero *CapitalShock*. The results in Table 5 show that the U-shaped impact of *CapitalShock* on firm risk-taking remains in three out of four specifications except that the *CapitalShock* coefficient becomes insignificant in the nonlife subsample with positive *CapitalShock* (i.e., decreased regulatory pressure). Consistent with our model predictions, some firms with low capital-adequacy levels increase their risk-taking when the regulatory pressure increases.

The above results confirm the existence of a cutoff point, at which the impact of *CapitalShock* on asset risk-taking reverses its direction. We are thus able to conclude in both nonlife and life insurance industries that insurers with solvency ratios below certain *SolvencyRatio* thresholds do not respond to additional regulatory pressure in the way that the regulator expects. In other words, the adverse impact of the regulatory reform is identified in both the life and nonlife samples. Higher regulatory pressure induces more asset risk-taking among low-solvency insurers to whom the solvency capital regulation should bind most tightly. The results are consistent with H2b, i.e., insurers with low capital-adequacy levels aggressively take more risks under a more stringent regulatory policy because they simply cannot meet the new requirements with the low-risk low-return portfolio. They have to bid for high-risk high-return portfolios in order to have some hope of meeting the higher capital requirement. Our results are consistent with prior literature documenting abnormal insurer behavior near insolvency threshold (e.g., Cheng et al., 2019). For insurers in certain healthy solvency-ratio intervals, the impact of *CapitalShock* is consistent with the regulatory intention: Higher regulatory pressure reduces the asset risk-taking and lower pressure encourages more risk-taking.

[18] A potential explanation is as follows. Excessively capital-adequate insurers may have set aside some redundant capital to address the uncertainty associated with the upcoming reform. When the reform was implemented, such uncertainty was realized and the redundant capital was no longer necessary. This capital was then unlocked, allowing more risk-taking behavior as expected from shareholders in pursuit of higher profits. A similar capital-unlocking pattern can be identified for nonlife insurers with *SolvencyRatio*>643.0%.

The identified adverse impact of regulatory reform is unintended from the regulator's perspective for two reasons. First, the adverse impact---i.e., an insurer takes more risks when it is subject to a higher regulatory pressure---is present only among low-solvency firms, of which the regulator should want to reduce risk-taking mostly. Second, there might be some changes in a regulatory reform to encourage risk-taking in specific asset classes and/or insurance LOBs. For example, C-ROSS encourages long-term equity investment and long-term traditional life insurance (Fung et al., 2018).[19] It is noteworthy that the risk-taking activities we analyze in this paper are the aggregate asset risk and aggregate portfolio risk, which can hardly be the intention of any regulator to encourage. Our empirical evidence also suggests that the C-ROSS reform reduces the industry-wide asset risk in both nonlife and life sectors.

Moreover, we show that this differential impact of regulatory pressure shock is not random and is also not an underlying trend in the Chinese insurance market. As shown in Table 6, the impact of *CapitalShock* does not exist (Columns 1 and 3) in the ante-reform subsample of 2013-2015. The results in Columns 2 and 4 suggest that the impact of *CapitalShock* only appears in the post-reform subsample of 2016-2017. In Appendix C3, we present additional and consistent results to show the impact of *CapitalShock* in each year from 2013 through 2017.

[19] C-ROSS imposes a risk factor of 15% for long-term equity investment and 31% for other equity investment to encourage long-term equity investment. Moreover, C-ROSS allows residual margins to be recognized as embedded surplus, which increases the eligible capital, particularly favor long-term life insurance underwriters, and thus steer the industry to long-term life insurance business (Fung et al., 2018).

Table 4 H2 Main Results (Dependent Variable: *ΔOAR*, Sample Period: 2013-2017)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Samples	**Nonlife**						**Life**					
Type of Threshold	**No**		**Regression-estimated**		**Regulatory attention**		**No**		**Regression-estimated**		**Regulatory attention**	
Estimation Method	**RE**	**IVRE**	**RE**	**IVRE**	**RE**	**IVRE**	**RE**	**IVRE**	**RE**	**IVRE**	**RE**	**IVRE**
CapitalShock	-0.00219	0.000997	-0.0119***	-0.00838**	-0.0453***	-0.0353**	-0.0132	-0.0121	-0.109**	-0.103**	-0.104**	-0.0982*
	(0.00351)	(0.00300)	(0.00459)	(0.00362)	(0.0113)	(0.0140)	(0.0118)	(0.0105)	(0.0482)	(0.0473)	(0.0514)	(0.0507)
CapitalShock × Threshold (≥285.5%)			0.0206***	0.0197***								
			(0.00380)	(0.00343)								
CapitalShock × Threshold (≥135.2%, <274.2%)									0.141***	0.138***		
									(0.0466)	(0.0468)		
CapitalShock × Threshold (≥274.2%)									0.0758	0.0714		
									(0.0492)	(0.0491)		
CapitalShock × Threshold (≥150.0%)					0.0445***	0.0377**					0.102*	0.0974*
					(0.0120)	(0.0144)					(0.0543)	(0.0550)
SolvencyI	0.773***	0.778***	0.766***	0.776***	0.926***	1.250***	1.072***	1.043***	1.289***	1.270***	1.292***	1.255***
	(0.0875)	(0.0894)	(0.0928)	(0.0959)	(0.230)	(0.256)	(0.0508)	(0.0533)	(0.244)	(0.236)	(0.185)	(0.178)
Other interaction variables	*No*		*SolvencyI × CapitalShock × Threshold, SolvencyI × CapitalShock, SolvencyI × Threshold, Threshold*				*No*		*SolvencyI × CapitalShock × Threshold, SolvencyI × Threshold, SolvencyI × CapitalShock, Threshold*			
Firm- and Year-specific control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	301	301	301	301	301	301	303	303	303	303	303	303
No. of insurers	62	62	62	62	62	62	66	66	66	66	66	66
Overall R^2	0.530	0.502	0.541	0.516	0.538	0.507	0.675	0.669	0.714	0.711	0.690	0.686

Notes: We report the coefficients of the random-effects panel regression and the EC-2SLS estimators of the random-effects IV panel regressions (Baltagi, 2013), in which *ROA*, *AssetGrowth*, and *AssetHHI* are instrumented with their one-year lag. The robust standard errors clustered at the insurer level are provided in parentheses. To account for the small sample size, we use t-statistics for statistical inferences with EC-2SLS estimators that are more conservative than the commonly used Z-statistics in random-effects models. *, **, and *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. The firm- and year- specific control variables are $SolvencyRatio_{t-1}$, $lnTotalAsset_{t-1}$, *ROA, AssetGrowth, AssetHHI, Group, Domestic, GDPGrowth,* and *IndustryGrowth.* Constants are included but not reported.

Table 5 Negative vs. Positive *CapitalShock* (Dependent Variable: *ΔOAR*, Sample Period: 2013-2017)

	(1)	(2)	(3)	(4)
Industry	**Nonlife**		**Life**	
Type of *CapitalShock*	***Negative***	***Positive***	***Negative***	***Positive***
CapitalShock	-0.00849**	0.0160	-0.122***	-6.019***
	(0.00418)	(0.125)	(0.0460)	(1.471)
CapitalShock × Threshold (≥285.5%)	0.0135***	0.423		
	(0.00422)	(0.453)		
CapitalShock × Threshold (≥135.2%, <274.2)			0.154***	6.233***
			(0.0442)	(1.422)
CapitalShock × Threshold (≥274.2%)			0.0855*	5.844***
			(0.0471)	(1.515)
SolvencyI	0.596***	0.986***	1.545***	-0.0624
	(0.173)	(0.180)	(0.0908)	(0.325)
Other interaction variables	*SolvencyI × CapitalShock × Threshold, SolvencyI × Threshold, SolvencyI × CapitalShock, Threshold*			
Firm- and year-specific CVs	*Yes*	*Yes*	*Yes*	*Yes*
Observations	191	110	212	91
No. of insurers	40	22	47	19
Overall R^2	0.545	0.589	0.705	0.793

Notes: The table reports the coefficients of the random-effects panel regressions. The robust standard errors clustered at the insurer level are provided in parentheses. *, **, and *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. The firm- and year- specific control variables are $SolvencyRatio_{t-1}$, $lnTotalAsset_{t-1}$, *ROA, AssetGrowth, AssetHHI, Group, Domestic, GDPGrowth,* and *IndustryGrowth.* Constants are included but not reported.

Table 6 After vs. Before the Reform (Dependent Variable: *ΔOAR*)

	(1)	(2)	(3)	(4)
Samples	**Nonlife**		**Life**	
Periods	**2013-2015**	**2016-2017**	**2013-2015**	**2016-2017**
CapitalShock	0.0177	-0.00979***	-0.0921	-0.0813**
	(0.0255)	(0.00277)	(0.0883)	(0.0366)
CapitalShock × Threshold (≥285.5%)	-0.0172	0.0246***		
	(0.0259)	(0.00442)		
CapitalShock × Threshold [135.2%, 274.2%)			0.109***	0.00210
			(0.0372)	(0.0929)
CapitalShock × Threshold (≥274.2%)			0.0817	0.0373
			(0.0920)	(0.0373)
Other interaction variables	*Threshold*			
Firm-specific CVs & Year fixed effects[a]	*Yes*	*Yes*	*Yes*	*Yes*
Observations	177	124	175	128
No. of insurers	62	62	65	64
Overall R^2	0.202	0.431	0.402	0.773

Notes: We report the coefficients of the random-effects panel regressions. The robust standard errors clustered at the insurer level are provided in parentheses. *, **, and *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. The firm-specific control variables are $SolvencyRatio_{t-1}$, $lnTotalAsset_{t-1}$, *ROA, AssetGrowth, AssetHHI, Group,* and *Domestic.* Constants are included but not reported.

a. In some subsample analyses with shorter panels, the macroeconomic control variables did not vary sufficiently over years (e.g., the GDP growth in China was very close in 2016 and 2017). Therefore, we use year fixed effects to replace the macroeconomic control variables in the subsample analyses.

To summarize, we document empirical evidence supporting (i) a positive relationship between capital adequacy and asset risk-taking (H1a) and (ii) a U-shaped impact of capital shock on asset risk-taking (H2b). Recall that C-ROSS is more stringent than Chinese Solvency I for two-thirds of insurers operating in China. This is particularly true for insurers with relatively low capital-adequacy levels as we observe only seven insurers be subject to regulatory attention (i.e., solvency ratio < 150%) under Chinese Solvency I while this number increased to 30 under C-ROSS. A significant fraction of insurers with low capital-adequacy levels was "overly stressed" by this reform. Instead of reducing asset risk, they absorbed more asset risk after the reform, hoping to retrieve their "lost" solvency ratios due to the reform with the high return from risky investments. According to our theoretical predictions, these low-capital-adequacy insurers were able to comfortably live with their solvency ratios under the moderate regulation of Chinese Solvency I (i.e., their solvency ratios were above the critical capital-adequacy threshold $1-(1-\delta)x/[1+\eta(\delta)]$), but became uncomfortable under the more stringent C-ROSS (i.e., their solvency ratios fell below the new threshold $1-(1-\delta)x/[1+\tilde{\eta}(\delta)]$).

5.3 Additional Results and Robustness Checks

Thus far, we focus on the asset risk-taking adjustments in response to a regulatory reform shock. Alternative options for insurers to a more stringent regulatory reform include (i) raising capitals using the internal capital market,[20] and (ii) adjusting the product risk or utilizing the diversification benefits between asset and product risks to reduce the aggregate portfolio risk. In this section, we present the additional results for the alternative options of insurers.

Insurers affiliated to an insurance or financial group may utilize internal capital market to optimally allocate available capital so as to alleviate the pressure on risk-taking adjustments. As a result, the adverse impact of regulatory pressure shock is less likely to appear in affiliated insurers than nonaffiliated insurers. We examine this assertion by adding the interaction term between *CapitalShock* and *Group* into Equation (3). The results in Columns (1) and (2) of Table 7 suggest that group affiliation partially (fully) mitigates the asset risk-taking pressure for nonlife (life) insurers. The results imply that insurers are reluctant to adjust their asset portfolio when they have alternative options, e.g., using the internal capital markets.

We reestimate Equation (3) using Δ*ProductRisk* ($\Delta\sigma_L$) and $\Delta VAL_{i,t}$ as dependent variables. Given that

[20] Capital regulation may not only affect the asset and product risk-taking behavior of financial institutions but also, in the long run, motivate institutions to raise external capitals if necessary (VanHoose, 2007). However, it is difficult for external financing in our short sample period after the C-ROSS reform (i.e., 2016-2017), and thus we do not observe a significant trend of capital flow after the reform.

we consider product risks, we also include $HHI\_LOB_{i,t}$ and $ReinsuranceCessionShare_{i,t}$ in the regressions to control for the product diversification and reinsurance use. Columns (2)-(6) of Table 7 suggest that the adverse impact of *CapitalShock* remains significant in both nonlife and life samples in terms of the aggregate portfolio risk, and significant in the life sample for product risk. These results are consistent with those of asset risk-taking and further demonstrate the robustness of our conclusion in that low-solvency insurers aggressively take more risks in response to additional regulatory pressure.

Table 7 Additional Results

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variables	***ΔOAR***		***ΔProductRisk***		***ΔVAL***	
Samples	**Nonlife**	**Life**	**Nonlife**	**Life**	**Nonlife**	**Life**
Estimated Thresholds	285.5%	135.2%[a]	218.5%	269.4%	218.5%	269.4%
CapitalShock	-0.0193***	-0.117**	-0.00289	-0.0344***	-0.00381*	-0.0369***
	(0.00494)	(0.0508)	(0.00199)	(0.00947)	(0.00209)	(0.00984)
CapitalShock ×	0.0132***	0.111*				
Group	(0.00493)	(0.0593)				
CapitalShock ×	0.0239***	0.153***	0.00250	0.0349***	0.00361	0.0380***
Above Threshold	(0.00705)	(0.0484)	(0.00216)	(0.0129)	(0.00241)	(0.0128)
SolvencyI	0.728***	1.578***	-0.0102	0.0924	-0.0281	0.0988
	(0.107)	(0.188)	(0.0326)	(0.102)	(0.0403)	(0.101)
Other Interaction Variables	Yes	Yes	Yes	Yes	Yes	Yes
Firm- and Year-specific control variables	Yes	Yes	Yes	Yes	Yes	Yes
Observations	301	303	301	302	296	301
No. of insurers	62	66	62	66	61	66
Overall R^2	0.549	0.725	0.024	0.082	0.060	0.087

Notes: We report the coefficients of the random-effects panel regression. The robust standard errors clustered at the insurer level are provided in parentheses. *, **, and *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. The firm- and year- specific control variables are $SolvencyRatio_{t-1}$, $lnTotalAsset_{t-1}$, *ROA, AssetGrowth, AssetHHI, Group, Domestic, GDPGrowth,* and *IndustryGrowth.* Constants are included but not reported.

a. The estimation includes the second threshold (274.2%) and its interactions in the life insurance sample. The reported coefficients of *CapitalShock × Above Threshold* are for *CapitalShock × Threshold [135.2%, 274.2%).*

To analyze the robustness of our results, we conduct the following six tests. The results of these tests are documented in Appendix D and are consistent with our main findings unless otherwise specified below. First, we use alternative asset risk measures, i.e., *RAR* and *RiskyAssetShare*. The significance of the *CapitalShock* coefficient declines in the *ΔRiskyAssetShare* regression for nonlife insurers, but its sign remains negative (see Table D1). Second, we apply alternative thresholds. We follow the literature and use sample terciles as the thresholds (nonlife thresholds are 234.5% and 372.0%; life thresholds are 191.0% and 283.0%) (see Table D2). The results are consistent with our main results. Third, we use the bootstrapped standard errors with 2,000 replications to account for the small sample size. The sign and significance of the *CapitalShock* coefficient remain unchanged for nonlife insurers, however, the coefficient significance slightly reduces to p-value=0.156 for life insurers (see Columns (1)-(2), Table D3). Fourth, to address the concern on outliers, we repeat our analyses with winsorized *CapitalShock* at 2nd and 98th percentiles of nonlife and life insurance samples, respectively, which is equivalent to censor the largest and smallest *CapitalShock* (see Columns (3)-(4), Table D3). All of our conclusions remain intact. Fifth, we repeat our analyses with *CapitalShock* in percentage to address the concern that the same difference in two solvency ratios may represent larger regulatory pressure change when the solvency ratio is small than when it is large. The results in nonlife insurance remain unchanged, whereas those in life insurance become less significant (see Columns (5)-(6), Table D3). Sixth, we estimate Equation (3) with firm fixed effects model. The coefficients of *CapitalShock × SolvencyI* are all positive, though two of them have lower significance levels. The results suggest that insurers with low solvency ratios increase (decrease) their risk-taking after the C-ROSS reform in response to a higher (lower) capital requirement comparing to their risk-taking levels before the reform. We cannot directly observe the net impact of *CapitalShock* after the reform because the coefficients of *CapitalShock* cannot be estimated due to the inclusion of firm fixed effects.

6. Policy Remedies

Our findings suggest that regulators should be mindful of the potential for the implementation of stricter capital regulations to backfire, causing firms with low capital-adequacy levels to take greater risks. In this section, we discuss three policy remedies for this unintended adverse impact, based on our theoretical and empirical analyses.

6.1 Increase the Regulatory Penalties

Our model in Section 3 indicates that a regulator can raise the regulatory cost c to mitigate the adverse effect of higher capital requirements. To see this, suppose that the post-reform regulatory policy $\tilde{\eta}(\cdot)$ imposes a higher regulatory pressure than the original policy $\eta(\cdot)$, which causes the adverse effect for firms with low capital-adequacy levels, i.e., $\psi \in \left(0, 1 - \frac{(1-\delta)x}{1+\tilde{\eta}(\delta)}\right]$, where $\delta \coloneqq max\{0, 1 - c/(y-2x)\}$. By Proposition 1, firms with $\psi \in \left(0, 1 - \frac{(1-\delta)x}{1+\tilde{\eta}(\delta)}\right]$ invest solely in the risky assets, and firms with $\psi \in \left(1 - \frac{(1-\delta)x}{1+\tilde{\eta}(\delta)}, 1\right)$ invest in both risky and safe assets.

Now suppose that $c < y - 2x$ and the regulator increases the regulatory cost from c to $\tilde{c}$. For notational convenience, denote $max\{0, 1 - \tilde{c}/(y-2x)\}$ by $\tilde{\delta}$. It follows immediately that $\tilde{\delta} < \delta$. By Proposition 1, the investment strategy of firms with $\psi \in \left(0, 1 - \frac{(1-\tilde{\delta})x}{1+\tilde{\eta}(\delta)}\right] \cup \left(1 - \frac{(1-\delta)x}{1+\tilde{\eta}(\delta)}, 1\right)$ remains unchanged. However, the increase in the regulatory cost varies the risk-taking incentive for firms with $\psi \in \left(1-\frac{(1-\tilde{\delta})x}{1+\tilde{\eta}(\tilde{\delta})}, 1-\frac{(1-\delta)x}{1+\tilde{\eta}(\delta)}\right]$: They reduce their holdings of the risky asset as Figure 3 illustrates. The above analysis demonstrates that the regulator can increase the regulatory cost to mitigate the adverse effect of a reform when the regulatory cost remains moderate.[21]

In practice, the regulator is able to increase the regulatory cost in many ways. For instance, the regulator can (i) restrict certain operations or the business development plan of the firm; (ii) restrict the authority and activities of the firm's management; (iii) increase fines to the firm and/or to the management; and/or (iv) temporarily take over the firm or suspend the firm's license. The above analysis demonstrates that increasing the penalties for capital-inadequate firms can correct the twisted incentives that occur due to a reform that raises the trigger threshold of regulatory intervention and/or increases the minimum capital requirements.

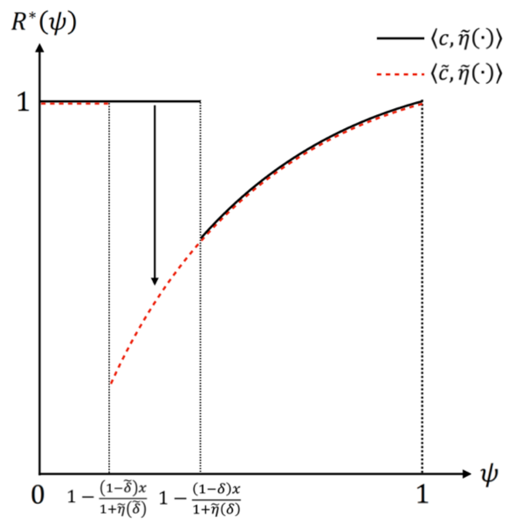


Figure 3 Impact of Increasing Regulatory Cost on Firm's Optimal Risk-taking Behavior

6.2 Increase the Risk Sensitivity of Capital Requirements

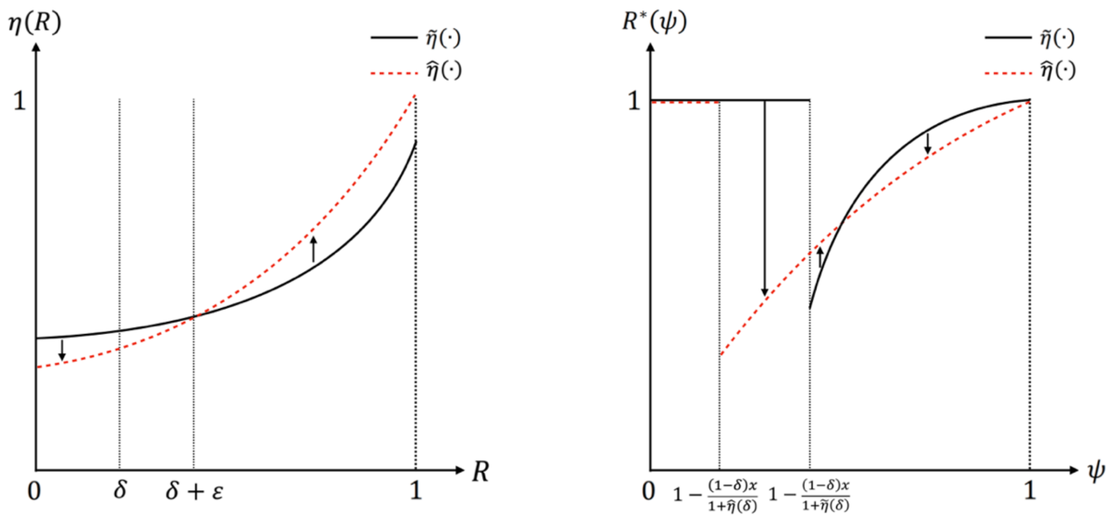
In addition to increasing regulatory penalties, the regulator can also adjust the required capital for given portfolios to mitigate the adverse impact of a reform. Specifically, the regulator can make the capital requirements more sensitive to the underlying risks by decreasing the required capital on safe assets and increasing the required capital on risky assets. In what follows, we demonstrate with our model how improved risk sensitivity restrains extreme risk-taking for firms with low capital-adequacy levels.

[21] This approach would lose its bite if the current regulatory cost is already sufficiently large, i.e., $c \geq y - 2x$. In such a scenario, further increasing the regulatory cost would not have a material impact.

Suppose that the post-reform regulatory policy $\tilde{\eta}(\cdot)$, which imposes a higher regulatory pressure than the original policy $\eta(\cdot)$, causes extreme risk-taking for low-capital-adequacy firms, i.e., $\psi \in \left(0, 1 - \frac{(1-\delta)x}{1+\tilde{\eta}(\delta)}\right]$. Recall that $\delta \coloneqq max\{0, 1 - c/(y - 2x)\}$. Consider the following adjustment. The regulator increases the minimum capital-liability ratio $\tilde{\eta}(\cdot)$ for portfolios with $R > \delta + \epsilon$ and decreases $\tilde{\eta}(\cdot)$ for $R < \delta + \epsilon$ (see the dotted curve $\hat{\eta}(\cdot)$ in Figure 4(a)), where $\epsilon > 0$ is small. In practice, such a design can be achieved by increasing the risk factor for risky assets and simultaneously decreasing the risk factor for safe assets.

The new regulation's improved risk sensitivity fundamentally reshapes the risk-taking incentive for some firms with low capital adequacy. Formally, consider firms whose initial capital-adequacy position ψ lies between $1 - \frac{(1-\delta)x}{1+\hat{\eta}(\delta)}$ and $1 - \frac{(1-\delta)x}{1+\tilde{\eta}(\delta)}$. These firms always incur a regulatory cost in the bad state when the return of the risky asset is low before the adjustment. As a result, they focus on the good state---the state where the return of the risky asset is high---when they decide on their risk-taking strategy and take the maximum risk ($R^* = 1$). Because the capital requirement decreases for firms that hold more safe assets and less risky assets, these firms would instead reconsider the bad state. Consequently, their risk-taking would drop dramatically from $R^* = 1$ to a low level, as the left downward arrow in Figure 4(b) indicates. Therefore, the unintended adverse impact of the reform is mitigated. Increasing the risk sensitivity of capital requirements further reduces the risk-taking behavior of capital-adequate firms. Because they were able to bear a large amount of risk under policy $\tilde{\eta}(\cdot)$, they would choose $R^* > \delta + \epsilon$. These firms would be subject to a higher minimum capital-liability ratio due to the increased capital requirement for risky assets and would reduce their risk (see the right downward arrow in Figure 4(b)).

However, increasing the risk sensitivity of capital requirements has its own expenses. To see this more clearly, note that firms that were moderately capital-adequate and chose $R^* \in (\delta, \delta + \epsilon)$ would face a slightly lower minimum capital-liability ratio and hence would experience lower regulatory pressure. As a result, they would increase their risk-taking after the policy adjustment (see the upward arrow in Figure 4(b)).



(a) Policy Adjustment to Improve Risk Sensitivity (b) Optimal Risk-taking Behavior

Figure 4 Risk Sensitivity of Capital Requirements and Firm's Optimal Risk-taking Behavior

To summarize, increasing the risk sensitivity of capital requirements can be an effective tool in a regulator's arsenal because it leads to a mass reduction in the extreme risk-taking behavior of low-capital-adequacy firms at the cost of a small increase in the risk-taking behavior of moderately capital-adequate firms.

6.3 Reinforce the Qualitative Risk Assessment (Pillar II) of Capital Regulation

Effective capital regulation in many banking and insurance markets (e.g., Basel III, Solvency II, and C-ROSS) is a three-pillar system. Pillar I refers to the quantitative capital requirements that we have modeled and empirically analyzed. Pillar I is the core of most capital regulation. Pillar II usually refers to the qualitative assessment of an institution's management of capital adequacy and risks.[22] The qualitative assessment is conducted by the institution itself, the regulator, or both. Pillar II also aims to ensure the risk-based capital adequacy of financial institutions and remedy the deficiencies of the quantitative capital requirements in Pillar I.

The qualitative risk assessment process in C-ROSS (i.e., SARMRA) is a scoring system that adjusts the quantitative capital requirements. No adjustment is made if an insurer has a SARMRA score of 80 out of 100. Insurers with a SARMRA score above (below, respectively) 80 receive a discount (loading,

[22] See, for instance, the Internal Capital Adequacy Assessment Process (ICAAP) and the Supervisory Review and Evaluation Process (SREP) in Basel III, the Own Risk and Solvency Assessment (OSAR) in RBC and Solvency II, and the Solvency Aligned Risk Management Requirements and Assessment (SARMRA) in C-ROSS.

respectively) on their required capital based on Pillar I.[23] The regulator rates most insurers every year by assessing their infrastructure, internal rules and processes, and capabilities to manage seven types of risks including insurance, market, credit, operational, strategic, reputational, and liquidity risks.

Next, we examine whether the qualitative risk assessment process (SARMRA) in C-ROSS can mitigate the unintended adverse impact of regulatory pressure shock driven by regulatory reform. Specifically, we estimate Equation (4) below in 2016-2017, the period when Solvency II was formally implemented and SARMRA scores are available.

$$\begin{aligned}\Delta OAR_{i,t} = {} & \beta_0 + \beta_1 CapitalShock_i + \beta_2 Threshold_i + \beta_3 SARMRA_{i,t} + \beta_4 CapitalShock_i \times Threshold_i \\ & + \beta_5 SARMRA_{i,t} \times CapitalShock_i + \beta_6 SARMRA_{i,t} \times Threshold_i \\ & + \beta_7 SARMRA_{i,t} \times CapitalShock_i \times Threshold_i + \beta_8 SolvencyRatio_{i,t-1} + \beta_9 X_{i,t} \\ & + \beta_{10} Year_t + \varepsilon_{i,t} \qquad (4)\end{aligned}$$

Table 8 Qualitative Risk Assessment (Dependent Variable: *ΔOAR;* Sample Period: 2016-2017)

	(1)	(2)	(3)	(4)
Samples	**Nonlife**		**Life**	
Models	**RE**	**IVRE**	**RE**	**IVRE**
CapitalShock	-0.0740	-0.129*	-0.851***	-0.831***
	(0.0653)	(0.0685)	(0.154)	(0.134)
CapitalShock × SARMRA	0.000834	0.00157*	0.0112***	0.0110***
	(0.000840)	(0.000885)	(0.00234)	(0.00203)
CapitalShock × Threshold (≥285.5%)	0.185**	0.259***		
	(0.0863)	(0.0892)		
CapitalShock × Threshold [135.2%, 274.2%)			0.943***	0.863***
			(0.181)	(0.177)
CapitalShock × Threshold (≥274.2%)			0.733***	0.687***
			(0.178)	(0.153)
Other interaction variables	*SARMRA × CapitalShock × Threshold, SARMRA × Threshold, Threshold, SARMRA*			
Firm-specific control variables	*Yes*	*Yes*	*Yes*	*Yes*
Year fixed effects	*Yes*	Yes	*Yes*	Yes
Observations	124	124	126	126
No. of insurers	62	62	63	63
Overall R^2	0.467	0.443	0.807	0.804

Notes: We report the coefficients of the random-effects panel regression and the EC-2SLS estimators of the random-effects IV panel regressions (Baltagi, 2013). The robust standard errors clustered at the insurer level are provided in parentheses. *, **, and *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. The firm-specific control variables are *$SolvencyRatio_{t-1}$, $lnTotalAsset_{t-1}$, ROA, AssetGrowth, AssetHHI, Group,* and *Domestic.* Constants are included but not reported.

[23] The adjustment formula is *MCR(Pillar II)*=(-0.005×*SARMRAScore*+0.4)×*MCR(Pillar I)*.

In Table 8, the coefficients of *CapitalShock* remain negative, suggesting that insurers with low solvency ratios increased their risk-taking when regulatory pressure increases. Importantly, the coefficients of the interaction term between *CapitalShock* and *SARMRA* are positive, indicating that insurers with low solvency ratios but with high SARMRA scores are less likely to counteract the regulation by taking greater risks. These results suggest that the qualitative risk assessment process in Pillar II mitigates the unintended adverse impact of *CapitalShock* for low-solvency insurers and thus partially remedies the deficiency of the regulatory reform. The results demonstrate the effectiveness of the qualitative risk assessment process in ensuring the capital adequacy of financial institutions (though it remains insufficient) and highlight its complementary role in capital-adequacy regulation and reform.

7. Conclusion

In this paper, we explore both theoretically and empirically the effects of regulatory pressure and regulatory reform on the risk-taking behavior of financial institutions. We first develop a theoretical framework that allows us to explicitly model risk-based and non-risk-based capital regulations. Our model predicts either a positive relationship or a U-shaped relationship between a firm's capital adequacy and its risk-taking behavior. We then introduce regulatory reforms into the model and examine firms' responses to changes in regulatory pressure. The model enables us to analyze two types of regulatory reforms: (i) change in the capital-adequacy threshold and/or (ii) change in the formula of capital-adequacy ratio or solvency ratio. Again, we show that two patterns may arise as capital regulations become more stringent: Either (i) all insurers uniformly reduce their risk-taking, or (ii) there exists a capital adequacy threshold below (above, respectively) which firms' risk-taking increases (decreases). The results and insights obtained in our model are robust across the banking and insurance sectors.

We then empirically test our theoretical predictions using a capital shock from a unique natural experiment (the Chinese solvency regulatory reform), which causes exogenous, unbiased, and insurer-specific changes in solvency ratios. Our empirical results are consistent with the model's predictions. Importantly, we identify the adverse impact of increased regulatory pressure on the risk-taking behavior of low-capital-adequacy insurers. These insurers are those that a regulator most wants to target for risk reduction. To the best of our knowledge, we are the first to document this unintended adverse impact of regulatory pressure on firms' risk-taking in the insurance sector, which are robust across life and nonlife insurance industries. We also document significant asset-risk reduction effects of solvency regulatory reform. This constitutes the first evidence of such effects outside the U.S. market.

The economic insights we uncover in this paper have important policy implications for the design of future capital regulation reforms. When the current regulatory policy is comfortable for most institutions, a regulator can uniformly reduce firms' risk-taking and provide better protection to consumers by instituting reforms with higher capital requirements. However, when the current regulatory policy is already tough for some institutions and the regulator calls for further reductions in risk-taking, a reform with higher capital requirements may have unintended adverse effect. In this case, a regulator should bundle the reform measures within its toolbox by not only raising the capital requirement but also increasing the regulatory penalties, increasing the risk sensitivity of capital requirements, and/or reinforcing the qualitative risk assessment (Pillar II). These policy remedies are effective tools for reducing the risk-taking incentives of low-solvency insurers, and may mitigate the unintended adverse impact of a regulatory reform.

There are several directions for future research. First, as mentioned in Section 3.3, we focus on firms' risk-taking behavior on either the asset side or liability side. It would be intriguing to extend our model to allow firms to take risks on both sides and examine their incentive for diversification. Second, to focus on the impact of regulatory reforms on risk-taking, this paper abstracts away the agency problem between manager and shareholders. It would be worthwhile to extend our model to incorporate this principal-agent relationship and explicitly model the incentive of the manager. Third, in mature markets, the adverse impact of a stricter regulatory reform may be gradually absorbed and is thus difficult to identify due to the long grace periods allowed for reform implementation. During such grace periods, firms can take long-term measures such as raising external capital, adjusting low-liquidity assets, and/or steering insurance lines of business to meet the new requirement. These are better alternatives than betting on high-risk, high-return business opportunities in the short term. It would be interesting to empirically analyze the impact of grace periods on mitigating the adverse effects of regulatory reform by comparing an unexpected reform like the Chinese one with a fully planned transition like the EU Solvency II reform.

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Appendix A Proofs

Appendix A1 Proof of Proposition 1

Proof. A firm's expected payoff can be rewritten as

$$\Pi(R) = \frac{1}{2} yR + x(1-R) + c \Pr\left(\frac{\psi + \pi(s,R)}{1-\psi} \geq \eta(R)\right) - c.$$

Moreover, $\frac{\psi+\pi(s,R)}{1-\psi} \geq \eta(R)$ can be written as

$$s \geq \frac{[1+\eta(R)](1-\psi) - x(1-R)}{yR}.$$

Because $s \in \{0,1\}$ and $\Pr(s=1) = 1 - \Pr(s=0) = 1/2$, we have that

$$\Pr\left(\frac{\psi + \pi(u,R)}{1-\psi} \geq \eta(R)\right) = \begin{cases} 1 & if\ \psi \geq 1 - \frac{x(1-R)}{1+\eta(R)}, \\ 0 & if\ yR + x(1-R) < [1+\eta(R)](1-\psi), \\ 1/2 & otherwise. \end{cases}$$

For notational convenience, let us define

$$g(R) \coloneqq 1 - \frac{x(1-R)}{1+\eta(R)}.$$

It is straightforward to verify that $g(R)$ is strictly increasing in R. Moreover, $g(0) = 1 - \frac{x}{1+\eta(0)}$ and $g(1) = 1$. Further, for $\psi \geq 1 - x/[1+\eta(0)]$, define $\hat{R}(\psi)$ as the unique solution to $g(R) = \psi$.

Similarly, let us define

$$h(R) \coloneqq yR + x(1-R) - [1+\eta(R)](1-\psi).$$

It can be verified that $h(0) = x - [1+\eta(0)](1-\psi)$, and $h(1) = y - [1+\eta(1)](1-\psi)$.

Assumption 3 implies that $h(1) > 0$ and $h(R)$ is weakly concave in R for all $R \in [0,1]$, which in turn implies that $h(R) = 0$ has at most one solution for $R \in [0,1]$. Specifically, for $\psi < 1 - x/[1+\eta(0)]$, $h(R) > 0$ for all $R \in [0,1]$. For $\psi \geq 1 - x/[1+\eta(0)]$, there exists a unique solution to $h(R) = 0$, which we denote by $\check{R}(\psi)$. Moreover, $h(R) > 0$ for $R > \check{R}(\psi)$ and $h(R) < 0$ for $R < \check{R}(\psi)$. It can be verified that $\check{R}(\psi) > \hat{R}(\psi)$.

We first ignore the non-negativity constraint of ψ and consider the following two cases, depending on firms' initial capital adequacy ψ relative to $1 - x/[1+\eta(0)]$.

Case I: $\boldsymbol{\psi} < 1 - \boldsymbol{x}/[\mathbf{1} + \boldsymbol{\eta}(\mathbf{0})]$. It can be verified that

$$\Pr\left(\frac{\psi + \pi(s,R)}{1-\psi} \geq \eta(R)\right) = \begin{cases} 0 & if\ R \leq \check{R}(\psi), \\ 1/2 & if\ R > \check{R}(\psi). \end{cases}$$

It follows from the above equality that increasing the fraction of risky portfolio R leads to a lower probability that regulatory intervention occurs. In other words, when the firm is less capital-adequate (i.e., $\psi < 1 - x/[1 + \eta(0)]$), increasing risk generates a higher expected return, which also leads to a (weakly) lower probability of being subject to regulatory intervention. As a result, $R^* = 1$.

Case II: $\boldsymbol{\psi \geq 1 - x/[1 + \eta(0)]}$. It can be verified that

$$\Pr\left(\frac{\psi + \pi(s, R)}{1 - \psi} \geq \eta(R)\right) = \begin{cases} 1 & if\ R \leq \hat{R}(\psi), \\ 1/2 & if\ R > \hat{R}(\psi). \end{cases}$$

In such a circumstance, the firm faces the tradeoff between a higher expected payoff and a higher probability of regulatory intervention when it decides on the holdings of risky portfolios. Importantly, the existence of such a tradeoff depends also on firm's investment decision R. To see this, note that firm's probability of avoiding regulatory intervention, i.e., $\Pr\left(\frac{\psi+\pi(s,R)}{1-\psi} \geq \eta(R)\right)$, is equal to 1 for $R \leq \hat{R}(\psi)$; and falls to $1/2$ for $R > \hat{R}(\psi)$. In other words, a well-capitalized firm can eliminate all possibility of being subject to regulatory intervention if a sufficiently large investment is placed in the safe portfolio.

The above analysis implies that $R^* = 1$ or $R^* = \hat{R}(\psi)$. It can be verified that $R^* = \hat{R}(\psi)$ if and only if

$$\left(\frac{y}{2} - x\right)\hat{R}(\psi) \geq \left(\frac{y}{2} - x\right) - \frac{c}{2}.$$

If $c \geq y - 2x$, then the above inequality holds for all $\psi \geq 1 - x/[1 + \eta(0)]$. If $c < y - 2x$, then the above inequality holds if and only if $\psi \geq \frac{c}{y-2x}x\Big/\left[1 + \eta\left(1 - \frac{c}{y-2x}\right)\right]$.

To summarize, if $c \geq y - 2x$, we have that

$$R^*(\psi) = \begin{cases} 1 & if\ \psi \in \left(0, 1 - \frac{x}{1+\eta(0)}\right], \\ \hat{R}(\psi) & if\ \psi \in \left(1 - \frac{x}{1+\eta(0)}, 1\right). \end{cases}$$

If $c < y - 2x$, we have that

$$R^*(\psi) = \begin{cases} 1 & if\ \psi \in \left(0, 1 - \frac{\frac{c}{y-2x}x}{1+\eta\left(1-\frac{c}{y-2x}\right)}\right], \\ \hat{R}(\psi) & if\ \psi \in \left(1 - \frac{\frac{c}{y-2x}x}{1+\eta\left(1-\frac{c}{y-2x}\right)}, 1\right). \end{cases}$$

Define $\delta := max\left\{0, 1 - \frac{c}{y-2x}\right\}$. It is evident that $\delta = 1 - \frac{c}{y-2x}$ for $c < y - 2x$ and $\delta = 0$ for $c \geq y - 2x$. Taking into account the non-negativity constraint of ψ, a firm's optimal portfolio choice is given by

$$R^*(\psi) = \begin{cases} 1 & if\ \psi \in \left(0, 1 - \frac{(1-\delta)x}{1+\eta(\delta)}\right], \\ \hat{R}(\psi) & if\ \psi \in \left(1 - \frac{(1-\delta)x}{1+\eta(\delta)}, 1\right), \end{cases}$$

if $1 - \frac{(1-\delta)x}{1+\eta(\delta)} > 0$, or equivalently, $\eta(\delta) + \delta x \geq x - 1$; and is given by

$$R^*(\psi) = \hat{R}(\psi)\ \forall\ \psi \in (0, 1),$$

if $\eta(\delta) + \delta x < x - 1$. ■

Appendix A2 Proof of Proposition 2

Proof. With slight abuse of notation, we add η into $R^*(\psi)$ and $\hat{R}(\psi)$ to emphasize that $\hat{R}(\psi)$ depends on $\eta(\cdot)$. Recall that $\hat{R}(\psi)$ (as defined in the proof of Proposition 1) is the solution to $g(R) \equiv 1 - \frac{x(1-R)}{1+\eta(R)} = \psi$ for $\psi \geq 1 - x/[1 + \eta(0)]$. It can be verified that $\hat{R}(\psi; \tilde{\eta}) < \hat{R}(\psi; \eta)$ for all $1 - x/[1 + \tilde{\eta}(0)] \leq \psi < 1$.

Note that $\delta \coloneqq max\left\{0, 1 - \frac{c}{y-2x}\right\}$ is independent of $\eta(\cdot)$. We consider the following two cases, depending on $\tilde{\eta}(\delta) + \delta x$ relative to $x - 1$.

Case I: $\boldsymbol{\tilde{\eta}(\delta) + \delta x} < x - 1$. It is straightforward to see that $\eta(\delta) + \delta x < \tilde{\eta}(\delta) + \delta x$. By Proposition 1, we can obtain that $R^*(\psi; \eta) = \hat{R}(\psi; \eta)$ and $R^*(\psi; \tilde{\eta}) = \hat{R}(\psi; \tilde{\eta})$ for all $\psi \in (0, 1)$. Moreover, we have that

$$R^*(\psi; \eta) = \hat{R}(\psi; \eta) > \hat{R}(\psi; \tilde{\eta}) = R^*(\psi; \tilde{\eta})\ \forall\ \psi \in (0, 1).$$

Therefore, all firms strictly decrease their investment in the risky asset in such a scenario.

Case II: $\boldsymbol{\tilde{\eta}(\delta) + \delta x > x - 1}$. It can be verified that $1 - \frac{(1-\delta)x}{1+\tilde{\eta}(\delta)} > 1 - \frac{(1-\delta)x}{1+\eta(\delta)}$. Firms with $\psi < 1 - \frac{(1-\delta)x}{1+\tilde{\eta}(\delta)}$ would (weakly) increase their investment in the risky asset from $R^*(\psi; \eta) \leq 1$ to $R^*(\psi; \tilde{\eta}) = 1$. Firms with $\psi > 1 - \frac{(1-\delta)x}{1+\tilde{\eta}(\delta)}$ would strictly decrease their investment in the risky asset from $\hat{R}(\psi; \eta)$ to $\hat{R}(\psi; \tilde{\eta})$. ■

Appendix B Robustness of Propositions

Appendix B1 Alternative Model Specification: Return from the Liability Side

In this part, we show that the baseline model we develop in Section 3 can be adapted to incorporate the possibility that firm makes risk-taking decision on the liability side. To this end, we assume that there is no investment opportunity available to the firm and the firm generates return solely from the liability side. There are two types of liability portfolios the firm can choose from: a safe product line that earns a deterministic return $x^\dagger$ per unit of liability, and a risky product line that generates either zero return or $y^\dagger > x^\dagger$ per unit of liability. The firm allocates a fraction $R \in [0,1]$ to the risky product line, and the rest to the safe one. Again, we use the variable $s \in \{0,1\}$ to indicate the outcome of the risky product line: $s = 1$ and $s = 0$ refer to the situations in which the gross return is $y^\dagger$ and 0, respectively. We assume that $\Pr(s = 1) = 1 - \Pr(s = 0) = 1/2$. Regulator uses a formula $f^\dagger(A, L, R)$, which satisfies Assumption 2, to determine the firm's minimum capital requirement, and the firm incurs a regulatory cost $c > 0$ if $K/f^\dagger(A, L, R) < \tau$. Similar to the argument in the main text, this condition is equivalent to $K/L < \eta^\dagger(R)$, where $\eta^\dagger(R)$ uniquely solves $f^\dagger\left(1 + 1/\eta^\dagger, 1/\eta^\dagger, R\right) = 1/\tau$.

Fixing a firm's product strategy $R \in [0,1]$ and the realized outcome of the risky product line $s \in \{0,1\}$, the firm's profit, denoted by $\pi^\dagger(s, R)$, can be derived as

$$\pi^\dagger(s, R) = y^\dagger(1 - \psi)sR + x^\dagger(1 - \psi)(1 - R) - (1 - \psi).$$

It is straightforward to verify that the firm's optimization problem can be written as

$$\max_{R \in [0,1]} \Pi^\dagger(R) := \frac{1}{2} y^\dagger(1 - \psi)R + x^\dagger(1 - \psi)(1 - R) - c \Pr\left(\frac{\psi + \pi^\dagger(s, R)}{1 - \psi} < \eta^\dagger(R)\right).$$

The above specification is isomorphic to the baseline model in Section 3 in which $x := x^\dagger\psi$, $y := y^\dagger\psi$, and $\eta(R) := \eta^\dagger(R) - \psi/(1 - \psi)$.

Appendix B2 Bankruptcy Costs

Next, we extend the model in Section 3 to capture the idea that a firm may be concerned about the possibility of becoming bankrupt when it makes its investment decision, and we show that Propositions 1 and 2 remain intact.

More formally, we assume that the firm incurs a cost $C > c$ when its capital-liability ratio is strictly less than zero, or equivalently, when the firm becomes bankrupt. Note that the extended model degenerates to the baseline when $C = c$.

For notational convenience, let us define

$$\delta' := max\left\{0, 1 - \frac{C}{y - 2x}\right\},$$

and

$$\overline{C} := c + (y - 2x)\frac{1 - \delta}{1 + \eta(\delta)},$$

where δ is defined in the main text as

$$\delta := max\left\{0, 1 - \frac{c}{y - 2x}\right\}.$$

Fixing a firm's initial capital adequacy ψ, we denote its optimal investment decision as $R^{**}(\psi)$. The following proposition reports the results, which are parallel to those in Proposition 1.

Proposition B1 (Optimal Portfolio Structure with Bankruptcy Costs) *Suppose that Assumptions 1, 2, and 3 are satisfied and* $C \in (c, \overline{C})$. *Then the following statements hold:*

i. *If* $\eta(\delta') + \delta' x < x - 1$, *then a firm's optimal investment decision is given by*

$$R^{**}(\psi) = \hat{R}(\psi)\ for\ all\ \psi \in (0, 1).$$

ii. *If* $\eta(\delta') + \delta' x \geq x - 1$, *then a firm's optimal investment decision is given by*

$$R^{**}(\psi) = \begin{cases} 1 & if\ \psi \in \left(0, 1 - \frac{(1-\delta')x}{1+\eta(\delta')}\right], \\ \hat{R}(\psi) & if\ \psi \in \left(1 - \frac{(1-\delta')x}{1+\eta(\delta')}, 1\right). \end{cases}$$

Proof. Fixing c, we follow the notation in the main text and denote a firm's expected payoff by $\Pi(\cdot)$ in the case where $C = c$. Further, denote by $\Pi_b(\cdot)$ a firm's expected payoff in the case $C > c$, where we use the subscript b to indicate "bankruptcy." It follows immediately that $\Pi_b(R) \leq \Pi(R)$ for all $R \in [0,1]$. Moreover, a firm's optimal investment strategy in the case $C = c$ corresponds to $R^*(\psi)$ as defined in Proposition 1. We consider the following two cases.

Case I: $\boldsymbol{R}^*(\boldsymbol{\psi}) = \boldsymbol{\hat{R}}(\boldsymbol{\psi})$. The firm can avoid regulatory intervention with probability 1 if it chooses $\hat{R}(\psi)$ in the case $C > c$. Therefore, the firm never becomes bankrupt with this investment strategy. This implies that $\Pi_b(\hat{R}(\psi)) = \Pi(\hat{R}(\psi))$. Together with the fact that $\Pi_b(R) \leq \Pi(R)$ for all $R \in [0,1]$, we have that $R^{**}(\psi) = \hat{R}(\psi)$.

Case II: $\boldsymbol{R}^*(\boldsymbol{\psi}) = \mathbf{1}$. First, note that a firm with capital adequacy ψ never becomes bankrupt when $s = 1$ for all $R \in [0,1]$, and becomes bankrupt when $s = 0$ if and only if $R > R_b := 1 - (1 - \psi)/x$. Second, note that $\Pi_b(R)$ is a piecewise linear function in R. Therefore, to prove the proposition, it suffices to show that choosing R_b is always sub-optimal to the insurer when $C < \overline{C}$.

Next, we show that $\Pi_b(1) > \Pi_b(R_2)$. Note that

$$\Pi_b(1) = \frac{y}{2} - \frac{C}{2},$$

and

$$\Pi_b(R_b) \leq \frac{1}{2} y R_b + x(1 - R_b) - \frac{c}{2},$$

where the inequality follows from the fact that a firm choosing R_2 would incur a regulatory cost c when $s = 0$. Combining the above two conditions, it suffices to show that

$$\frac{y}{2} - \frac{C}{2} > \frac{1}{2} y R_b + x(1 - R_b) - \frac{c}{2},$$

which is equivalent to

$$(y - 2x)(1 - R_b) > C - c.$$

Next, Proposition 1 and the postulated $R^*(\psi) = 1$ under $C = c$ imply that

$$\psi \leq 1 - \frac{(1-\delta)x}{1 + \eta(\delta)}.$$

Therefore, we have that

$$C - c < \overline{C} - c = \frac{(y - 2x)(1 - \delta)}{1 + \eta(\delta)} \leq \frac{(y - 2x)(1 - \psi)}{x} = (y - 2x)(1 - R_b).$$

To complete the proof, note that a firm becomes bankrupt under $R = 1$ and the cost to the insurer is C instead of c. Therefore, the optimal investment strategy under $C > c$ can be obtained by updating δ to δ' in Proposition 1. ■

The following comparative statics with respect to $\eta(\cdot)$ can then be established.

Proposition B2 (Impact of Regulatory Reform on Risk-taking with Bankruptcy Costs) *Suppose that Assumptions 1, 2, and 3 are satisfied, and* $C \in (c, \overline{C})$. *Consider a regulatory reform from* $\eta(\cdot)$ *to* $\tilde{\eta}(\cdot)$, *whereby firms are subject to a higher regulatory pressure under* $\tilde{\eta}(\cdot)$. *Then the following statements hold:*

i. *If* $\tilde{\eta}(\delta') + \delta' x < x - 1$, *then all firms strictly decrease their holdings of the risky asset.*

ii. *If* $\tilde{\eta}(\delta') + \delta' x > x - 1$, *then*

   a) *Firms with initial capital adequacy* $\psi \in \left(0, 1 - \frac{(1-\delta')x}{1+\tilde{\eta}(\delta')}\right)$ *weakly increase their holdings of the risky asset;*

b) Firms with initial capital adequacy $\psi \in \left(1 - \frac{(1-\delta')x}{1+\tilde{\eta}(\delta')}, 1\right)$ *strictly decrease their holdings of the risky asset.*

Proof. The proof is similar to that of Proposition 2 and is omitted for brevity. ■

Appendix B3 Non-constant Regulatory Costs

In this section, we provide some numerical results and show that the predictions established in Propositions 1 and 2 continue to hold with non-constant regulatory costs. To proceed, we parametrize $f(\cdot,\cdot,\cdot)$ by $(\theta_1, \theta_2, \theta_3)$ as follows:

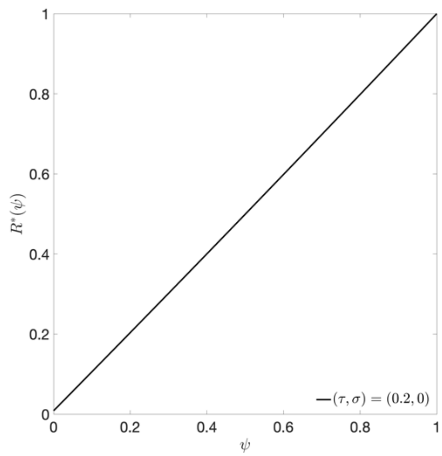
$$f(A, L, R) = \theta_1 AR + \theta_2 A(1 - R) + \theta_3 L, with\ \theta_1 \geq \theta_2 \geq 0\ and\ \theta_3 \geq 0.$$

Note that the capital regulation is risk-based if $\theta_1 > \theta_2$ and is non-risk-based if $\theta_1 = \theta_2$. Further, we adopt the cost function in Section 3.3 and assume that firms incur no regulatory costs if $K/f(A, L, R) \geq \tau$ and incur a regulatory cost $\mathcal{C}$ in the form of

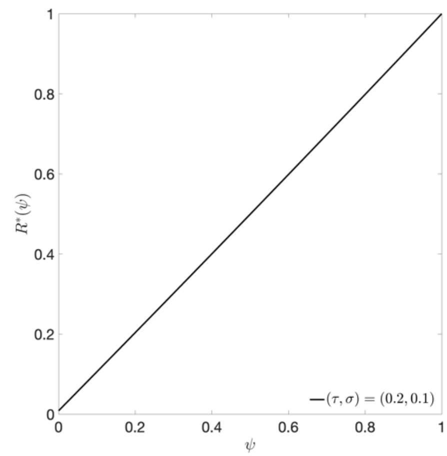
$$\mathcal{C} := c + \sigma\left[\tau - \frac{K}{f(A, L, R)}\right], with\ \sigma \geq 0, if\ \frac{K}{f(A, L, R)} < \tau.$$

Robustness of Proposition 1 Suppose that $(x, y, c) = (1.05, 3, 1)$, $(\theta_1, \theta_2, \theta_3) = (0.2, 0.1, 0.1)$, and $(\tau, \sigma) \in \{0.2, 1\} \times \{0, 0.1, 0.2\}$. Figure B1 depicts firms' optimal portfolio choice under different combinations of $\text{ and } \sigma$. Recall that the regulatory cost is constant when $\sigma = 0$. By Figures B1(a)-B1(c), the monotonic relationship between firms' capital-adequacy position ψ and their risk-taking behavior R^* is preserved as σ increases from 0 to 0.2. Similarly, the U-shaped relationship between ψ and R^* depicted in Figure B1(d), where $\sigma = 0$, also appears in Figures B1(e) and B1(f), where σ takes values of 0.1 and 0.2, respectively. Note that $R^*(\psi)$ in Figure B1(f) is continuous and U-shaped in ψ.

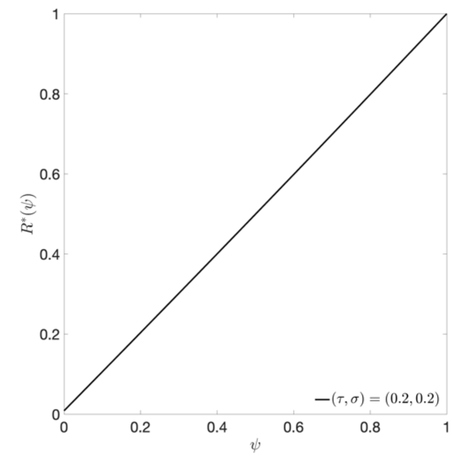
Robustness of Proposition 2 Next, we consider firms' change in their investment strategy when the capital regulation becomes more stringent, captured by an increase in θ_1 or an increase in τ. Again, we set $(x, y, c) = (1.05, 3, 1)$, $(\theta_2, \theta_3) = (0.1, 0.1)$. In addition, let $(\sigma, \tau, \theta_1) \in \{0.1, 0.2\} \times \{0.2, 0.7, 1.0, 1.5\} \times \{0.2, 0.3\}$. Figures B2(a)-B2(d) depict the impact of a regulatory reform on firms' optimal risk-taking behavior with non-constant regulatory costs. The solid curve in each figure delineates firms' optimal investment strategy before the reform. The dashed curves represent firms' optimal investment strategy when θ_1 increases, holding τ fixed. The dash-dotted curves represent firms' optimal investment strategy when τ increases, holding θ_1 fixed. Consistent with the predictions in Proposition 2, Figures B2(a)-B2(d) suggest that either all firms reduce their risk-taking, or that there exists a capital-adequacy threshold below which (above which, respectively) firms' risk-taking increases (decreases) as regulation becomes stricter.



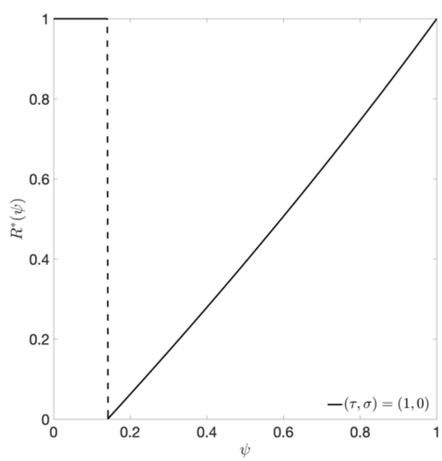
(a) $(\tau, \sigma) = (0.2, 0)$



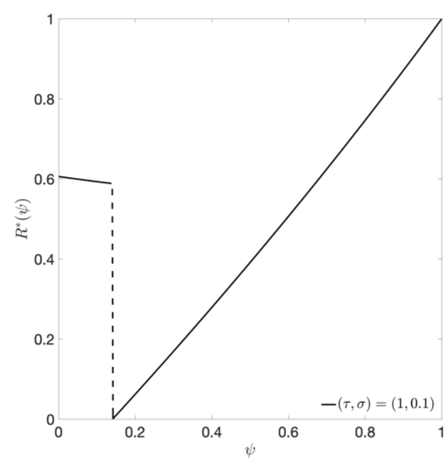
(b) $(\tau, \sigma) = (0.2, 0.1)$



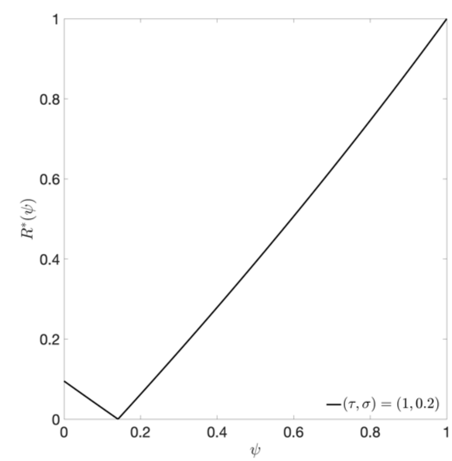
(c) $(\tau, \sigma) = (0.2, 0.2)$



(d) $(\tau, \sigma) = (1.0, 0)$

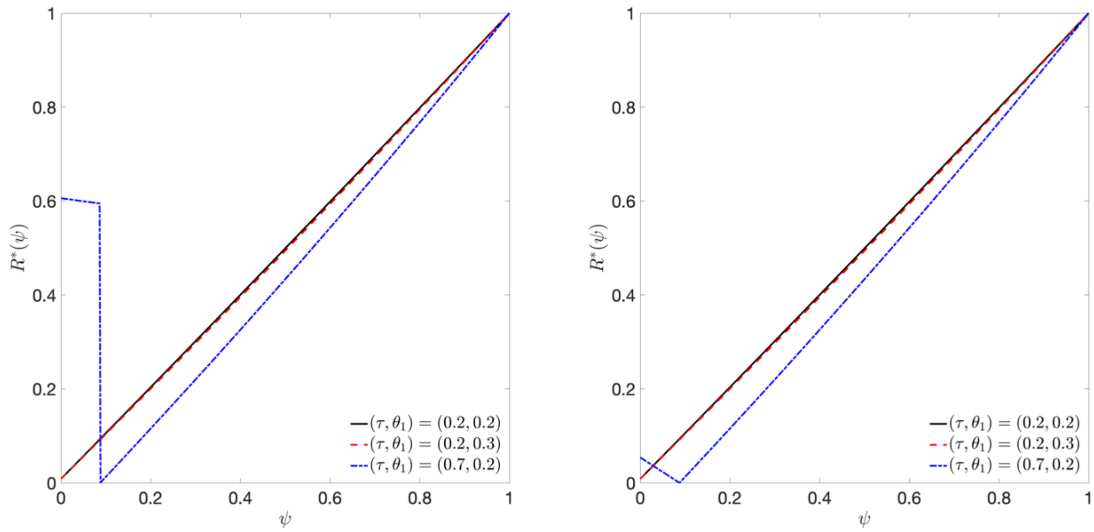


(e) $(\tau, \sigma) = (1.0, 0.1)$

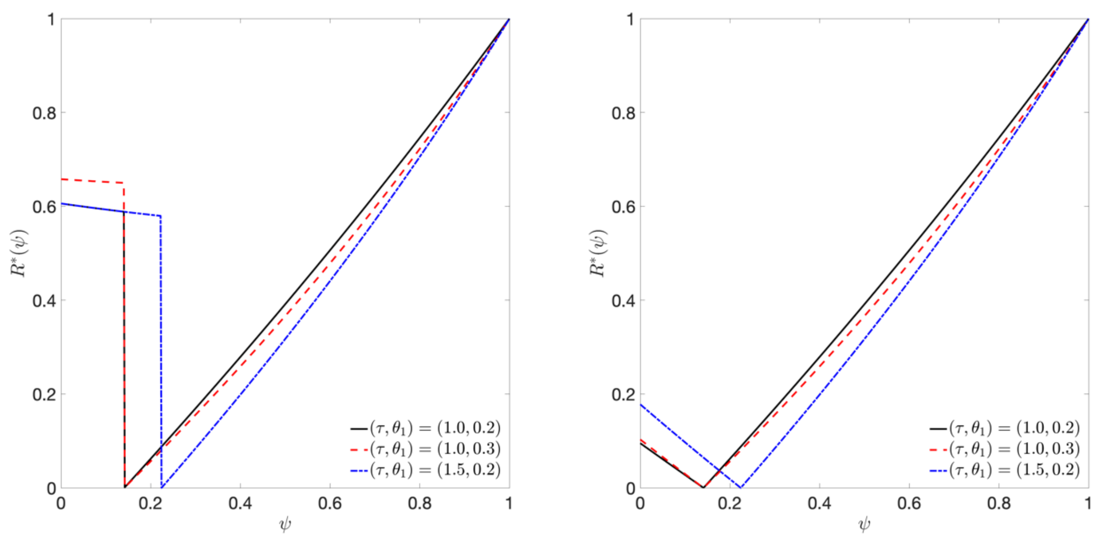


(f) $(\tau, \sigma) = (1.1, 0.2)$

Figure B1 Firm's Optimal Portfolio Structure with Non-constant Regulatory Costs



(a) $\sigma = 0.1, \tau \in \{0.2, 0.7\}, \theta_1 \in \{0.2, 0.3\}$ (b) $\sigma = 0.2, \tau \in \{0.2, 0.7\}, \theta_1 \in \{0.2, 0.3\}$



(c) $\sigma = 0.1, \tau \in \{1.0, 1.5\}, \theta_1 \in \{0.2, 0.3\}$ (d) $\sigma = 0.2, \tau \in \{1.0, 1.5\}, \theta_1 \in \{0.2, 0.3\}$

Figure B2 Impact of Regulatory Reform on Firm's Optimal Risk-taking with Non-constant Regulatory Costs

Appendix C Additional Results

Appendix C1 Threshold Regressions

Table C1 Threshold Regressions (Sample Period: 2016-2017)

	(1)	(2)	(3)	(4)
Dependent Variables	***ΔOAR***		***ΔVAL***	
Samples	**Nonlife**	**Life**	**Nonlife**	**Life**
First Threshold	285.5%	135.2%	218.5%	234.1%
Second Threshold		274.2%		269.4%
CapitalShock_Region1	-0.00978***	-0.0809**	-0.0113	-0.0356***
	(0.00306)	(0.0335)	(0.00702)	(0.0104)
CapitalShock_Region2	0.0148***	0.0284***	-3.47e-05	-0.372***
	(0.00413)	(0.00765)	(0.00149)	(0.0522)
CapitalShock_Region3		-0.0445***		-0.000466
		(0.0807)		(0.00917)
Control variables	Yes	Yes	Yes	Yes
Observations	124	128	122	127
No. of insurers	62	64	61	64
AIC	-204.00	-274.80	-353.59	-188.7

Notes: We report the estimated thresholds and the regression coefficients of the threshold regressions (Hansen, 1999; Lin et al., 2014). White robust standard errors are provided in parentheses. *, **, and *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. The control variables are $SolvencyRatio_{t-1}$, $lnTotalAsset_{t-1}$, *ROA, AssetGrowth, AssetHHI, Group, Domestic, GDPGrowth,* and *IndustryGrowth.* Constants are allowed to vary in different *SolvencyRatio* intervals but are not reported.

Appendix C2 Alternative Baseline Firms

In Table 4 of Section 5.2, we present the main results for Hypothesis 2, where we use firms with *SolvencyRatio* below the first threshold as the baseline group in the life and nonlife samples. Therefore, the coefficients of *CapitalShock* in Table 4 directly capture the impact on the baseline firms that belong to the lowest *SovlencyRatio* region. In Table C2 below, we alternatively use firms in higher *SolvencyRatio* regions as the baseline group by omitting other *Threshold* variables. The respective coefficients of *CapitalShock* thus directly capture the impact on firms in higher *SolvencyRatio* regions. We thus can interpret the results more straightforwardly.

Table C2 Alternative Omitted Thresholds (Dependent Variable: *$\triangle$OAR;* Sample Period: 2013-2017)

	(1)	(2)	(3)	(4)	(5)
Samples	**Nonlife**		**Life**		
Type of Threshold	**Regression-estimated**	**Regulatory attention**	**Regression-estimated**		**Regulatory attention**
CapitalShock	0.00871**	-0.000768	0.0321***	-0.0329***	-0.00251
	(0.00367)	(0.00330)	(0.00794)	(0.00665)	(0.00913)
CapitalShock × Threshold (<285.5%)	-0.0206***				
	(0.00380)				
CapitalShock × Threshold (<135.2%)			-0.141***	-0.0758	
			(0.0466)	(0.0492)	
CapitalShock × Threshold (≥135.2%, <274.2)				0.0650***	
				(0.00728)	
CapitalShock × Threshold (≥274.2%)			-0.0650***		
			(0.00728)		
CapitalShock × Threshold (<150.0%)		-0.0445***			-0.102*
		(0.0120)			(0.0543)
SolvencyI	0.743***	0.750***	1.046***	1.097***	1.039***
	(0.111)	(0.0893)	(0.0579)	(0.0797)	(0.0516)
Other interaction variables	*SolvencyI × CapitalShock × Threshold, SolvencyI × Threshold, SolvencyI × CapitalShock, Threshold*				
Firm- and year-specific CVs	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	301	301	303	303	303
No. of insurers	62	62	66	66	66
Overall R^2	0.541	0.538	0.714	0.714	0.690

Notes: The table reports the coefficients of the random-effects panel regressions. The robust standard errors clustered at the insurer level are provided in parentheses. *, **, and *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. The firm- and year-specific control variables are *$SolvencyRatio_{t-1}$, $lnTotalAsset_{t-1}$, ROA, AssetGrowth, AssetHHI, Group, Domestic, GDPGrowth,* and *IndustryGrowth.* Constants are included but not reported.

Appendix C3 Impact of Capital Shock in Each Year

We analyze the impact of *CapitalShock* in each year from 2013 through 2017. The results in Columns 1-3 and 6-8 of Table C3 suggest that the impact of *CapitalShock* does not exist in 2013, 2014, or 2015 for nonlife and life insurers. Columns 4 and 9 suggest that the impact of *CapitalShock* in 2016 is insignificant for nonlife insurers and significant for life insurers. Interestingly, Columns 5 and 10 suggest the opposite in 2017: The impact is significant for nonlife insurers but insignificant for life insurers. Together, these results suggest that nonlife insurers take longer to respond to regulatory reform than life insurers. These results might be driven by the generally higher solvency ratios of nonlife insurers relative to life insurers. Compared with nonlife insurers, life insurers are under immediate pressure and thus are in a hurry to release the regulatory pressure by adjusting their asset portfolios.

Table C3 Impact of *CapitalShock* in Each Year (Dependent Variable: *ΔOAR*)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Samples			**Nonlife**					**Life**		
Sample Periods		**2013-2015**		**2016-2017**			**2013-2015**		**2016-2017**	
CapitalShock	-0.00683 (0.0569)	0.0193 (0.0365)	0.186 (0.112)	0.0215 (0.0148)	-0.0132*** (0.00420)	0.00632 (0.152)	0.130 (0.178)	0.0457 (0.155)	-0.0918*** (0.0333)	-0.00361 (0.0463)
CapitalShock × Threshold (≥285.5%)	0.00350 (0.0569)	-0.0169 (0.0386)	-0.184 (0.113)	-0.00702 (0.0159)	0.0293** (0.0142)					
CapitalShock × Threshold (≥135.2%)						-0.175 (0.161)	-0.175 (0.161)	-0.0733 (0.168)	0.115*** (0.0324)	0.0340 (0.0470)
CapitalShock × Threshold (≥274.2%)						-0.0528 (0.157)	-0.128 (0.181)	-0.0528 (0.157)	0.0743** (0.0350)	-0.0477 (0.0476)
Other interaction variables	*Year14 × CapitalShock* *Year15 × CapitalShock* *Year × CapitalShock × Threshold* *Year × Threshold* *Threshold* *Year*	*Year13 × CapitalShock* *Year15 × CapitalShock* *Year × CapitalShock × Threshold* *Year × Threshold* *Threshold* *Year*	*Year13 × CapitalShock* *Year14 × CapitalShock* *Year × CapitalShock × Threshold* *Year × Threshold* *Threshold* *Year*	*Year17 × CapitalShock × Threshold* *Year17 × Threshold* *Threshold* *Year17*	*Year16 × CapitalShock × Threshold* *Year16 × Threshold* *Threshold* *Year16*	*Year14 × CapitalShock* *Year15 × CapitalShock* *Year × CapitalShock × Threshold* *Year × Threshold* *Threshold* *Year*	*Year13 × CapitalShock* *Year15 × CapitalShock* *Year × CapitalShock × Threshold* *Year × Threshold* *Threshold* *Year*	*Year13 × CapitalShock* *Year14 × CapitalShock* *Year × CapitalShock × Threshold* *Year × Threshold* *Threshold* *Year*	*Year17 × CapitalShock × Threshold* *Year17 × Threshold* *Threshold* *Year17*	*Year16 × CapitalShock × Threshold* *Year16 × Threshold* *Threshold* *Year16*
Firm-specific CVs	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	177	177	177	124	124	175	175	175	128	128
No. of insurers	62	62	62	62	62	65	65	65	64	64
Overall R^2	0.208	0.208	0.208	0.452	0.452	0.429	0.429	0.429	0.791	0.791

Notes: We report the coefficients of random-effects panel regressions. The robust standard errors clustered at the insurer level are provided in parentheses. *, **, and *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. The firm-specific control variables are $SolvencyRatio_{t-1}$, $lnTotalAsset_{t-1}$, *ROA, AssetGrowth, AssetHHI, Group,* and *Domestic.* Constants are included but not reported.

Appendix D Robustness Tests

We use two alternative asset risk measures, regulatory asset risk (RAR, Baranoff et al., 2007) and the share of equity and alternative investments (RiskyAssetShare, Gaver and Pottier, 2005). RAR uses the U.S. RBC system as the benchmark regulatory standard to estimate an "unbiased" asset risk for each insurer from the perspective of a third party. We estimate the weighted risk factor for each insurer in each year based on the insurer's asset structure, and then take the natural logarithm of it to obtain the *RAR* measure. We consolidate the assets into five classes (cash, bonds, equity, real estate, and alternative investments) to match the RBC asset classes. The corresponding RBC risk factors are taken from Liu et al. (2019).

$$RAR_{i,t} = \ln\left(\frac{\sum_{a=1}^{5} Asset_{i,t,a} \times RiskFactor_a}{TotalInvestedAsset_{i,t} + Cash_{i,t}}\right),$$

and

$$RiskyAssetShare_{i,t} = \frac{Equity_{i,t} + Fund_{i,t} + Securitization_{i,t} + Derivative_{i,t} + Other_{i,t}}{TotalInvestedAsset_{i,t} + Cash_{i,t}}.$$

Table D1 Alternative Asset Risk Measures (Sample Period: 2013-2017)

	(1)	(2)	(3)	(4)
Samples	**Nonlife**		**Life**	
Dependent Variables	***ΔRAR***	***ΔRiskyAssetShare***	***ΔRAR***	***ΔRiskyAssetShare***
CapitalShock	-0.00996**	-0.000554	-0.113***	-0.0208***
	(0.00469)	(0.000356)	(0.0350)	(0.00570)
CapitalShock × Threshold (≥285.5%)	0.0146*	0.000990*		
	(0.00782)	(0.000585)		
CapitalShock × Threshold (≥135.2%, <274.2)			0.136***	0.0236***
			(0.0352)	(0.00628)
CapitalShock × Threshold (≥274.2%)			0.105***	0.0210***
			(0.0365)	(0.00594)
SolvencyI	-0.117	0.00545	0.313	0.274**
	(0.116)	(0.0181)	(0.310)	(0.133)
Other interaction variables	*SolvencyI × CapitalShock × Threshold, SolvencyI × Threshold, SolvencyI × CapitalShock, Threshold*			
Firm-specific and year-specific control variables	*Yes*	*Yes*	*Yes*	*Yes*
Observations	301	301	303	303
No. of insurers	62	62	66	66
Overall R^2	0.196	0.052	0.338	0.214

Notes: The table reports the coefficients of the random-effects panel regressions. The robust standard errors clustered at the insurer level are provided in parentheses. *, **, and *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. The firm- and year-specific control variables are *$SolvencyRatio_{t-1}$, $lnTotalAsset_{t-1}$, ROA, AssetGrowth, AssetHHI, Group, Domestic, GDPGrowth,* and *IndustryGrowth.* Constants are included but not reported.

Table D2 Tercile as Thresholds (Dependent Variable: *ΔOAR;* Sample Period: 2013-2017)

Sample	(1) **Nonlife**	(2) **Life**
CapitalShock	-0.0219*** (0.00528)	-0.0463** (0.0201)
CapitalShock × Threshold (≥234.5%, <372.0%)	0.0174*** (0.00545)	
CapitalShock × Threshold (≥372.0%)	0.0316*** (0.00770)	
CapitalShock × Threshold (≥191.0%, <283.0%)		0.0834*** (0.0218)
CapitalShock × Threshold (≥283.0%)		0.0130 (0.0219)
SolvencyI	0.814*** (0.0987)	1.301*** (0.0999)
Other interaction variables	*SolvencyI × CapitalShock × Threshold, SolvencyI × Threshold, SolvencyI × CapitalShock, Threshold*	
Firm- and year-specific control variables	*Yes*	*Yes*
Observations	301	303
No. of insurers	62	66
Overall R^2	0.554	0.707

Notes: We report the coefficients of the random-effects panel regressions. The robust standard errors clustered at the insurer level are provided in parentheses. *, **, and *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. The firm- and year-specific control variables are $SolvencyRatio_{t-1}$, $lnTotalAsset_{t-1}$, *ROA, AssetGrowth, AssetHHI, Group, Domestic, GDPGrowth,* and *IndustryGrowth.* Constants are included but not reported.

Table D3 Bootstrapped Standard Errors, Winsorized *CapitalShock*, and *CapitalShock* in Percentage (Dependent Variable: *ΔOAR*, Sample Period: 2013-2017)

	(1)	(2)	(3)	(4)	(5)	(6)
Tests	**Bootstrapped Standard errors**		**Winsorized *CapitalShock***		***CapitalShock* in %**	
Samples	**Nonlife**	**Life**	**Nonlife**	**Life**	**Nonlife**	**Life**
CapitalShock	-0.0119*	-0.109[a]	-0.0174***	-0.109**	-0.248**	-0.226
	(0.00626)	(0.0766)	(0.00402)	(0.0481)	(0.0990)	(0.468)
CapitalShock × Threshold	0.0206***		0.0262***		0.493***	
(≥285.5%)	(0.00620)		(0.00598)		(0.158)	
CapitalShock × Threshold		0.141*		0.150***		0.497
(≥135.2%, <274.2)		(0.0784)		(0.0453)		(0.495)
CapitalShock × Threshold		0.0758		0.0643		-0.0910
(≥274.2%)		(0.0793)		(0.0496)		(0.502)
SolvencyI	0.766***	1.289***	0.781***	1.266***	0.761***	1.102***
	(0.0911)	(0.401)	(0.0917)	(0.227)	(0.0890)	(0.266)
Other Interaction Terms	*SolvencyI × CapitalShock × Threshold, SolvencyI × Threshold, SolvencyI × CapitalShock, Threshold*					
Firm- and year-specific CVs	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	301	303	301	303	301	303
No. of insurers	62	66	62	66	62	66
Overall R^2	0.541	0.714	0.542	0.708	0.541	0.681

Notes: The table reports the coefficients of the random-effects regressions. The bootstrapped standard errors with 2,000 replications are provided in brackets and the robust standard errors clustered at the insurer level are provided in parentheses. *, **, and *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. The firm- and year-specific control variables are $SolvencyRatio_{t-1}$, $lnTotalAsset_{t-1}$, *ROA, AssetGrowth, AssetHHI, Group, Domestic, GDPGrowth,* and *IndustryGrowth.* Constants are included but not reported.

a. P-value=0.156.

Table D4 Fixed-Effects Model (Dependent Variable: ΔOAR, Sample Period: 2013-2017)

	(1)	(2)	(3)	(4)
Samples	**Nonlife**		**Life**	
Type of Threshold	**Regression-estimated**	**Regulatory attention**	**Regression-estimated**	**Regulatory attention**
CapitalShock × SolvencyI	0.0483[a]	1.114***	0.143[b]	0.180**
	(0.0382)	(0.306)	(0.102)	(0.0862)
CapitalShock × Threshold (≥285.5%)	0.0206***			
	(0.00554)			
CapitalShock × Threshold (≥135.2%, <274.2%)			0.168***	
			(0.0457)	
CapitalShock × Threshold (≥274.2%)			0.105**	
			(0.0512)	
CapitalShock × Threshold (≥150.0%)		0.0619***		0.140**
		(0.0184)		(0.0556)
SolvencyI	0.723***	1.206***	1.497***	1.482***
	(0.0922)	(0.316)	(0.274)	(0.209)
Other interaction variables	*SolvencyI × CapitalShock × Threshold, SolvencyI × Threshold*			
Firm- and year-specific control variables	*Yes*	*Yes*	*Yes*	*Yes*
Observations	301	301	303	303
No. of insurers	62	62	66	66
Overall R^2	0.587	0.588	0.743	0.723

Notes: The table reports the coefficients of the firm fixed-effects panel regressions. The robust standard errors clustered at the insurer level are provided in parentheses. *, **, and *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. The firm- and year-specific control variables are $SolvencyRatio_{t-1}$, $lnTotalAsset_{t-1}$, *ROA, AssetGrowth, AssetHHI, GDPGrowth,* and *IndustryGrowth.* Constants are included but not reported.

a. p-value=0.211.

b. p-value=0.165.