Regulatory Differences and Shadow Insurance: Cross-border Impact of Insurance Prudential Regulation*

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Abstract

Little is known about the cross-border impact of insurance prudential policies. Using a regulatory change in the European Union (EU), known as the Solvency II reform, as a quasi-natural experiment, we study the cross-border impact of the insurance prudential regulation on the risk and capital dynamics in a foreign (U.S.) market. We find that EU affiliated insurers in the U.S. appear to improve their financial strength compared to U.S. domestic insurers due to the more stringent Solvency II reform. Meanwhile, we also find that EU affiliated insurers cede more risks through shadow insurance to a third country due to the higher regulatory pressure. The seemingly improved financial strength of EU affiliated insurers disappears after adjusting for the use of shadow insurance. The results indicate that the regulatory transmission effect of prudential regulation is offset by the arbitrage effect of shadow insurance.

Keywords: Prudential Regulation; Regulatory Transmission; Regulatory Arbitrage; Shadow Insurance; Capital Regulation; Solvency Regulation

JEL Codes: G22; G28

1 Introduction

The global financial crisis manifests the systemic risk of the insurance sector in a financial system. The AIG failure followed by government bail-out suggests the systemic importance of large insurers to the financial system as final risk bearers. In 2013, nine global insurance groups from Europe, U.S., and China were designated as “systemically important insurers” by the Financial Stability Board. On the asset side, insurers are the largest institutional investors in the corporate bond market (Becker and Ivashina, 2015; O’Hara et al., 2018). Shocks to insurers are transmitted to banks and the real economy through fire-sales in capital markets (Ellul et al., 2011, 2015). On the liability side, insurers protect businesses and households. The insurance product market transmits shocks to the rest of the economy (Koijen et al., 2016). Further, insurers are interconnected with banks as counterparties of derivative transactions (e.g., credit default swaps), aggravating liquidity problems in recessions. Given the systemic importance of the insurance sector, there exists surprisingly scarce literature on insurance prudential policies and their cross-border impacts.

The insurance sector offers a laboratory environment to analyze the cross-border impact of financial prudential regulation. Banks reallocate risks and capitals across borders by increasing/decreasing international lending (Aiyar et al., 2014; Forbes et al., 2017), through securitization, through branches and subsidiaries of multinational banks (Ongena et al., 2013), and through cross-border mergers and acquisitions (Karolyi and Taboada, 2015). These international bank flows are subject to national cross-border capital regulations, e.g., the foreign exchange regulation (Ahnert et al., 2021), which to some extent impose barriers, add costs, and consume time for banks to reallocate risks and capitals internationally. Reinsurance including shadow insurance (Koijen and Yogo, 2016), however, enables insurers to transfer and reallocate insurance risks across boarders on a regular basis with low cost, in a timely manner, and with less regulatory restrictions. In other words, the international reinsurance market has a higher degree of freedom for risk flows (and equivalently insurance capital flows) across borders (Biener et al., 2017) and therefore it is easier to observe the strategic responses of insurers to prudential regulation and its changes. Additionally, insurers have higher variaties of asset portfolio composition than banks and thus can be more freely to decide and have more tools to achieve an targeted risk composition (Ge and Weisbach, 2021).

In this study, we investigate a prudential regulatory change in the insurance sector—the Solvency II reform in the European Union—and its cross-border impact on insurers' financial strength and on their risk and capital dynamics. Solvency II is three-pillar capital adequacy regime with microprudential and macroprudential impacts (EIOPA, 2018; Deloitte, 2019; Milliman, 2020). It sets a much higher capital adequacy standard than the Risk-based Capital Standards (RBC) in the U.S.. Solvency II would require twice as much capital for a representative U.S. property-casualty (P/C) insurer as RBC does (Liu et al., 2019).

Prior literature analyzing the impact of banking prudential regulation highlights the identification challenges due to the reverse causality—the introduction of prudential regulation was, at least in part, in response to bank risk-taking and macroeconomic developments (Houston et al., 2012; Ongena et al., 2013; Aiyar et al., 2014; Frame et al., 2020). To address this concern, we exploit a quasi-natural experiment by the cross-border impact of the Solvency II reform penetrated into the U.S. market, where (i) the risk-taking and capital adequacy of the U.S. insurers should not be a major consideration in designing the European regulation and (ii) it forms naturally a treatment group and a control group depending on whether the U.S. insurer is subject to the regulation of Solvency II.

Specifically, we analyze a sample of P/C insurers incorporated in the U.S., the largest insurance market worldwide. We categorize our sample insurers into EU affiliated and U.S. domestic firms. EU affiliated firms are insurers incorporated in the U.S. and affiliated to or having an affiliated EU entity under the regulation of Solvency II; U.S. domestic firms are insurers incorporated in the U.S. and neither affiliated to nor having an affiliated entity in the EU. EU affiliated insurers are subject to both RBC and Solvency II because of the group consolidated supervision requirement in the Title III of Solvency II (Directive/2009/138/EC;

EIOPA-BoS-14/181), while U.S. domestic insurers are subject to RBC and possibly the regulation of a third market but not Solvency II.

When financial prudential regulations are different across markets, regulatory transmission and/or arbitrage may arise. On the one hand, the more prudential capital standards of Solvency II may be transmitted from EU insurers to their affiliated entities in the U.S. market (i.e., EU affiliated insurers) through the international operation of multinational insurance groups (Aiyar et al., 2014; Forbes, 2021). This regulatory transmission hypothesis predicts that prudential regulations transmit higher regulatory standards across markets. On the other hand, cross-border regulatory differences may generate unintended regulatory arbitrages (Houston et al., 2012; Ongena et al., 2013), where a financial group takes advantage of the lower regulatory standards in some markets to reallocate their risks and capital to these markets (Houston et al., 2012; Karolyi et al., 2018; Frame et al., 2020). While regulatory transmission reduces risks and/or increases capital holdings in less regulated markets; regulatory arbitrage reallocates risks to these markets, resulting in a heightened insolvency risk in less regulated markets.

In the context of Solvency II reform, the regulatory transmission effects increase the solvency standards of EU affiliated insurers operating in the U.S. market; the regulatory arbitrage opportunities allow international financial groups to reallocate some risks to markets having less stringent regulation than Solvency II such as the U.S. market and the offshore-shadow insurance markets (Koijen and Yogo, 2016). Prior literature documents that banks use shadow banking and life insurers use shadow insurance to circumvent prudential policies (Koijen and Yogo, 2016; Buchak et al., 2018; Chen et al., 2020). Will insurers race to the bottom of the prudential regulation by hiding their risks (and profits) in affiliated, unrated, and unauthorized reinsurers that are in the shadow of insurance prudential regulation?

Using a difference-in-difference (DID) empirical design, we show that EU affiliated insurers appear to improve their overall financial strength (measured by A.M. Best ratings) compared to U.S. domestic insurers after the Solvency II reform. We then test the risk-taking, capital, and reinsurance adjustment channels, through which the improved financial strength can be achieved. We find that EU affiliated insurers reduce asset and underwriting risk-taking compared to U.S. domestic insurers. Our results suggest that the EU affiliated insurers that are individually capitalized in the U.S. practice more prudently in the U.S. markets than U.S. domestic insurers. The more prudent Solvency II seems to successfully transmit to the U.S. market, since otherwise we would have observed non-results. We attribute this regulatory transmission from EU to the U.S. insurance market to the group solvency regulation of Solvency II that internalizes portfolios of all regulated and identifiable entities in an insurance group. Our results support the regulatory transmission hypothesis.

Moreover, we find that EU affiliated insurers incorporated in the U.S. market cede more insurance business to affiliated, unauthorized, and unrated reinsurers that are in the shadow of any prudential regulation compared to the U.S. domestic insurers after the Solvency II reform. The evidence of increasing use of shadow insurance supports the regulatory arbitrage hypothesis. To account for the risk of shadow insurance, we estimate adjusted A.M. Best ratings following Koijen and Yogo (2016). We find that the seemingly improved financial strength of EU affiliated insurers disappears after adjusting for shadow insurance use, indicating that the regulatory transmission effects of Solvency II are completely offset by the regulatory arbitrage effect of shadow insurance.

Literature and Contribution Our work makes three contributions to the literature. First, we contribute to identifying the causal impact of prudential regulations that are challenging due to reverse causality and omitted variable problems (Houston et al., 2012; Ongena et al., 2013; Aiyar et al., 2014; Frame et al., 2020; Forbes, 2021). Overall, we establish a causal relation between prudential regulations and multinational financial institutions' financial strength and risk flows. The Solvency II reform and our design to analyze its impact on the U.S. insurance market establish an ideal quasi-natural experiment environment, where the treated group of EU affiliated insurers were affected by the Solvency II reform, the control group of U.S. domestic insurers were not, and insurers are more convenient and with lower cost to transfer their insurance risk across markets than banks. Few studies use a DID research design in studying prudential regulation, as which usually applies to all market players simultaneously. Ahnert et al. (2021) compare changes in banks' and industrial corporates' borrowing and debt issuance to control for any omitted variables that affect each type of entities or borrowings. However, one may argue that banks and industrial firms are not quite comparable. In our setting, the treatment and control groups of insurers both incorporate in the U.S. insurance market and thus are better matches. Also, previous work on cross-border regulatory differences focuses on either capital flow (e.g., Karolyi and Taboada, 2015) or risk transmissions (e.g., Barth et al., 2004; Frame et al., 2020). We investigate how regulatory differences affect the joint decision of risk and capital reallocation across markets.

Second, our study contributes to the ongoing discussion on shadow insurance by documenting the first piece of evidence on the use of shadow insurance in the P/C insurance industry. We find that P/C insurers have increasingly used shadow insurance in response to regulatory pressure, showing that shadow insurance use is not unique to life insurers. Proponents of shadow insurance argue that it frees up capital required for redundant reserves (M Financial Group, 2013; Harrington, 2015), lowers insurance price, and improves market efficiency (Koijen and Yogo, 2016). Concerns for shadow insurance include that it can increase the overall risk of a financial group (Koijen and Yogo, 2016; Hepfer et al., 2020) and increase the expected loss for the insurance industry, which may endanger the stability of the broader financial system (NYDFS, 2013; Koijen and Yogo, 2014, 2016). Shadow insurance is also associated with lower liquid asset holdings, increased credit risk, and shifting U.S. profits to tax havens (Hepfer et al., 2020). We join the opponents of using shadow insurance and support additional regulation for shadow insurance by providing new evidence that shadow insurance use is associated with heightened overall insolvency risk, offsets the positive effects of a tightening prudential regulation, and thus undermines the goals of prudential regulations.

Third, to the best of our knowledge, this is the first study examining the cross-border impacts of prudential regulation in the insurance sector. The systemic importance of the insurance sector and its potential different responses to prudential regulations from banks warrants a separate study. Importantly, while banking literature finds that regulatory arbitrage usually counteracts a small to moderate portion of the direct effects of domestic regulations (Ahnert et al., 2021), we find that shadow insurance completely offsets the positive effects of insurance prudential regulation.

Our findings have important policy implications. Regulators are advised to take into account both the regulatory transmission effects and the arbitrage effects in the shadow of prudential regulation when designing the regulatory standards for multinational financial institutions. Our work is also relevant to the effectiveness of group solvency regulation and its global impacts.

The rest of the paper is structured as follows. In Section 2, we summarize the institutional background. Section 3 develops a simple theoretical model and our hypotheses. Section 4 describes our sample and key variables. Section 5 presents the empirical design. Section 6 reports the results and discusses alternative explanations. We conclude in Section 7.

2 Institutional Background and Literature Review

2.1 The Solvency II Reform

The Solvency II reform shifts the insurance solvency regulation in the EU from volume-based capital requirements under Solvency I to risk-based capital requirements (Eling and Holzmüller, 2008).[1] The main objective of Solvency II is to ensure insurers hold sufficient economic capital to meet their financial claims from policyholders and to reduce the probability of insurer failure (Boonen, 2017). The Solvency II reform is a more stringent regulatory

[1] As a member of EU, UK was also under the Solvency II regulation before the end of Brexit transition period in 1 January 2021. Since that, the UK insurance market has been regualted by the Prudential Regulation Authority (PRA) and Financial Regulation Authority (FCA) using the amended Solvency II. (Milliman, 2021)

reform that increases the capital and other requirements for insurers compared to Solvency I (Eling et al., 2007).

Solvency II features three pillars following the Basel framework for banks. Pillar I sets out the quantative capital requirements that consider both asset and liability risks of an insurer's balance sheet. Both internal and standardized risk models can be used to calculate the capital requirements. The breach of capital requirements compliance would result in regulatory interventions, for example, fines, bans on selling new policies, or forced closure of the company, among others. Pillar II focuses on the superviosry review of qualitative solvency standards including risk management and corporate governance. It requires insurers to regularly conduct Own Risk and Solvency Assessment (ORSA) that identifies the areas that may deviate from solvency requirements and how to address them. Pillar III emphasizes the disclosure requirements aiming to increase the transparency of insurers' financial conditions and to promote stronger market discipline.

Solvency II emphasizes group level supervision to both domestic and international, financial and insurance groups. The capital requirements of Solvency II apply to both operating firm level and consolidated group level. The impact of Solvency II is thus transmitted beyond its jurisdiction (i.e., the EU market) through groups that have EU operations including both EU based groups and non-EU based groups.

For an EU based group, the group capital requirements incorporate the financial information of all its subsidiaries worldwide. By default, the group solvency calculation is carried out according to the accounting consolidation-based method, so called "Method 1" in Solvency II.[2] Both the group own fund and the group solvency capital requirements (SCR) are determined based on a group's consolidated accounts prepared in accordance with the International Financial Reporting Standards (IFRS) (European Commission, 2019). Solvency II allows EU affiliated insurers operating in non-EU markets to use the local capital standards

[2]More than 90% of EU financial and insurance groups apply the default "Method 1" (European Commission, 2019). When the accounting method is considered inappropriate according to criteria listed in Article 328 of the Commission Delegated Regulation (EU) 2015/35, Method 2 (i.e., deduction and aggregation methods) or a combination of methods 1 and 2 can be used to determine the group SCR.

to determine their operating company level SCR as long as the local capital regulation is deemed equivalent to Solvency II, for example, the U.S. RBC. The Solvency II, however, can still influence the risk and capital decisions of the EU affiliated insurers operating in non-EU markets through its group capital requirements. Regulators require group capital add-on to adjust for the SCR if group specific risk is not adequately reflected by standard formula or internal model. Regulators can also apply capital add-on at each subsidiary within the group if it is deemed necessary (CEIOPS, 2009). These measures in Solvency II increase the pressure of subsidiaries of an EU based group including the foreign affiliations to improve their capital adequacy according to Solvency II standards. In addition, the group supervision of Solvency II under Pillars II and III requires EU affiliated insurance subsidiaries operating in non-EU markets to meet certain risk management and reporting standards and therefore reinforces their prudent business activities (SOA, 2011).

For a non-EU based group, the firm level capital requirements of Solvency II are applied directly at all the subsidiaries operating in the EU markets. The group level capital requirements are also applied at the highest level operating entity in the EU, which incorporate the financial information of its worldwide subsidiaries.

Solvency II follows a similar risk-based capital adequacy philosophy as RBC but requres much higher capital requirements than RBC (Braun et al., 2014; Laas and Siegel, 2017; Liu et al., 2019). The inconsistencies between Solvency II and RBC are large. The standard method of Solvency II requires twice as much as the capital that RBC requires for a representative U.S. P/C insurer (Liu et al., 2019). According to the regulatory equivalence rule, Solvency II allows EU affiliated insurers operating in the U.S. market to use RBC rules, the relatively low capital standards, to determine their operating company level SCR as RBC is deemed provisional equivalent to Solvency II. However, the higher standards of Solvency II are still applied to the consolidated accounts to determine the group level SCR. Therefore, the Solvency II reform is expected to increase the regulatory pressure for EU affiliated insurers operating in the U.S. market to adopt a higher standard. On the flip side, the heightened solvency regulation standards may increase the cost of EU affiliated insurers operating in the U.S. market and reduce their competitiveness relative to the U.S. domestic insurers.[3]

The Solvency II was officially implemented in January 2016. Its impact, however, started much earlier from the release of two milestone documents that are the official Solvency II Directive (2009/28/CE) published in November 2009 and the final Quantitative Impact Study (QIS5) published in July 2010. The Solvency II Directive sets the fundamental theme of the Solvency II framework and serves as the foundation for all subsequent revisions. The QIS5 evaluates the difference of capital requirements between Solvency I and Solvency II, and highlights that Solvency II would lead to a 43% reduction of group surplus in excess of the regulatory requirements compared to Solvency I if using the standard model. These two documents serves as the rigorous guidelines for EU insurers to assess their risk and capital profiles under the new regulatory regime and to take corresponding actions preparing their adaptation to Solvency II. Therefore, in following empirical analyses, we consider 2010 as the event year of the Solvency II reform and consider the risk and capital profiles at the end of 2010 as the beginning of post-reform adjustments.[4] Most insurance companies have already met the Solvency II capital requirements before its effectiveness (Höring, 2013).

2.2 Shadow Insurance

Shadow insurance is the type of reinsurance that an insurer uses to move its liabilities from regulated and rated entities that sell the insurance policies to shadow reinsurers that are usually captives or special purpose vehicles domiciled in the jurisdictions with more favorable capital or tax regulations (Koijen and Yogo, 2016). Originally, captives were formed by non-insurance companies to insure their parent company's own risks. It has been widely used in the property and casualty lines. In general, captives are operated like regular commercial

[3]The U.S. insurance regulators started the regulatory reform–Solvency Modernization Initiative (SMI) since 2008. The SMI applies to all insurers operating in the U.S. insurance market including both U.S. domestic insurers and EU affiliated insurers. Our results are thus less affected by SMI with the DID empirical design.

[4]In Section 6.4, we conduct a standard event study to verify our choice of 2010 as the event year of Solvency II reform and the results support our choice.

insurance or reinsurance companies. However, the main differences are that capitves typically only insure the risks of their parent or affiliated companies and are subject to very little capital requirements. Capitves can write premiums five to fifteen times more than a regular insurers for the same amount of capital.

Different from using captives as a form of self-insurance by non-insurance companies, capitves can also be formed by insurance companies for the purposes of cirvumvent stringent regulation. Therefore, Koijen and Yogo (2016) define shadow insurance as the reinsurance ceded to affiliated, unauthorized, and unrated captives or other special purpose vehicles. Koijen and Yogo (2016) document that the rapid growth of shadow insurance use in the life insurance industry is spurred by the adoption of Valuation of Life Insurance Policies Model Regulation 830 (commonly referred to as Regulation XXX) and Actuarial Guideline 38 (Regulation AXXX) in 2000. The new regulations raise statutory reserve requirement on term life insurance and universal life insurance with second guarantees. Higher reserve requirement forces life insurers to hold more capital to meet the RBC standards. Shadow reinsurers are not subject to RBC regulation and report financial information under GAAP, a less stringent accounting principle than Statutory Accounting Principles (SAP). In addition, shadow insurance transactions can be funded by letters of credit. Altogether, shadow reinsurers can take more risks than an RBC regulated insurer given the same amount of capital. Life insurers have been increasingly ceding more business to shadow reinsurers to circumvent the capital regulation. The total liabilities ceded through shadow insurance has exceeded the amount of unaffiliated reinsurance in the life insurance industry in 2012 (Koijen and Yogo, 2016). To reduce the incentive for life insurers to use shadow insurance, the Actuarial Guideline XLVIII (AG 48, effective in 2015) reduces the stingentcy of reserve requirements by moving from the rule-based reserve requirements to principle-based requirements (NAIC, 2021).

Solvency II may impose additional capital pressure on EU affiliated insurers operating in the U.S. market through its group supervision, compared to U.S. domestic insurers, to which only RBC applies. Thus, like the reserve requirement changes, the Solvency II reform and the inconsistencies between Solvency II and RBC standards may provide similar incentives for EU affiliated insurers to use shadow insurance to bypass the higher capital requirements and to maintain their competititveness compared to their U.S. domestic peers.

Shadow insurance was less popular but also possible in the P/C insurance industry (NAIC, 2013). The NAIC subgroup of "Captives and Special Purpose Vehicles" summarizes the common insurance product lines that are allowed to be transferred from an insurance company to captives or special purpose vehicles, including life, casualty, marine and transportation, marine protection and indemnity, property, liability, surety title, credit life, credit disability, among others. Captives were originally formed and used within the Casualty insurance industry to allow entities to deduct premiums paid to the capitve insurance company in one year for losses that may be paid out over a number of years (NYDFS, 2013). Thus, it is worth to also examine the shadow insurance use of P/C insurers. We analyze the P/C insurers also because they usually respond to regulatory changes faster than life insurers due to shorter product duration and thus better fit to capture the risk dynamics after a regulatory shock.

2.3 Regulatory Transmission and Regulatory Arbitrage

The cross-border transmission effects of financial regulation refer to the case when one market imposes, for example, a stricter regulation, its impacts transmit beyond the market border.[5] A stricter regulation may reduce the risk-taking and/or increase the capital holdings of financial institutions not only in the home market of the regulation but also spills over to other markets, when firms of the home market expand their business operation to the host market and bring along the high quality governance due to the stricter regulation in the home market (Rossi and Volpin, 2004; Bris and Cabolis, 2008). Cross-border transmission may result in increased firms' investment efficiency (Chen et al., 2013), global contraction of

[5] The term "transmission effects" and "spillover effects" are often used interchangeably in the literature (e.g. Buch et al., 2017; Aiyar et al., 2014).

foreign lending (Forbes et al., 2017), and negative local firm-level real effects (Morais et al., 2019).

Existing evidence on cross-border M&As shows that target firms in markets with poorer investor protection and lower quality of accounting standards tend to follow the governance structure of acquiring countries with higher investor protection and accounting standards (Rossi and Volpin, 2004; Bris and Cabolis, 2008). The evidence from banking shows that the prudential regulation policies transmit cross borders through lending reallocations across different markets (Buch et al., 2017; Franch et al., 2021). Thus, a regulatory transmission hypothesis predicts that a stricter regulation in the home market shall increase the financial strength of affiliated institutions in the host market, thereby reducing their insolvency risk.

On the flip side, regulatory arbitrage may arise when the financial regulation in one market is inconsistent with that in another market. Regulatory arbitrage allows international financial groups to circumvent financial regulation by transferring risks from markets with more stringent regulation to markets with less stringent regulation (Houston et al., 2012; Karolyi and Taboada, 2015). Regulatory arbitrage has been blamed to weaken the financial stability during the 2008 financial crisis because of the excessive risk-taking in the less regulated markets (Acharya and Richardson, 2009).

Existing evidence of regulatory arbitrage shows fund flows of banks to less regulated markets (Freixas et al., 2007; Karolyi et al., 2018), excessive risk-taking due to lowering lending standards in foreign markets (Barth et al., 2004; Ongena et al., 2013; Houston et al., 2012; Frame et al., 2020), and risk shifting to shadow banks and shadow reinsurers (Buchak et al., 2018; Koijen and Yogo, 2016). Therefore, a regulatory arbitrage hypothesis predicts that the regulatory inconsistency across markets allows institutions in less regulated markets to take excessive risks, thereby increasing their insolvency risk.

Following the rationale of regulatory arbitrage hypothesis, there must be some markets having even lower capital requirements and even less regulated than the U.S., for example, Bermuda and Cayman Islands. Therefore, EU affiliated insurers under Solvency II pressure should prefer to (further) transferring their risks to these markets via, for example, shadow insurance. Shadow insurance thus offers a lower capital cost in a less regulated market.[6] In this sense, a "smart" EU affiliated insurer should embrace the higher standards of Solvency II in appearance by "hiding" some risks to its shadow reinsurers to keep its competitiveness to U.S. domestic insurers. In other words, EU affiliated insurers should find alternative capital at lower cost and in the shadow of Solvency II to circumvent the higher capital requirements.

3 A Simple Model and Hypothesis Development

We develop a simple model of an insurer's joint decisions on investment, insurance price, and shadow insurance use to illustrate the impact of the Solvency II reform on EU affiliated insurers operating in the U.S. market. We make several simplifying assumptions to focus on the key economic insights. First, our baseline model captures the asset risk adjustment in response to the Solvency II reform. Our results, however, can be easily adapted to models with underwriting risk adjustment (see Appendix B for the model extension). Second, we do not model external equity issuance because raising external equity is more costly than using reinsurance due to financial market friction (Myers and Majluf, 1984; Koijen and Yogo, 2016).[7]

We consider a regulated framework where an operating insurer may be affected by two layers of solvency regulation. Any operating insurer is subject to the domestic capital regulation. If the operating insurer is affiliated to a foreign insurance group, it is also subject to a stricter group solvency regulation of the foreign market. Thus, the affiliated operating insurer faces the choice between maintaining risk-based capital associated with lower domestic capital regulation and improving risk-based capital according to the higher foreign

[6]EU based captives are regulated by Solvency II directly. In contrast, third country based captives receive the same credit for their reinsurance transactions as EU based reinsurers as long as the regulatory system in the third country is deemed equivalent to Solvency II (e.g., Bermuda, U.S., etc.).

[7]Capital regulation may in the long run motivate institutions to raise external capitals if necessary VanHoose (2007). However, according to the Pecking Order Theory, external capital is also more expensive than retained earnings and internal capital market. We thus follow Koijen and Yogo (2016) to control for the capital position of each insurer in later empirical analyses, which accounts for capital dynamics.

capital regulation. As the benchmark, we first develop the basic model for an unaffiliated operating insurer without considering the group solvency regulation. The insurer in this case represents the U.S. domestic insurers. We then extend our model to allow for the potential transmission effects of group solvency regulation. The insurer in the extended model represents the EU affiliated insurers. Shadow insurance (as a type of regulatory arbitrage) is allowed in both model specifications. We compare the impact of solvency regulation on the equilibria of the two models to develop our hypotheses. We use superscripts '*' and '**' to denote the equilibrium variables in the basic model and extended model, respectively.

3.1 Basic Model

We consider a regulated economy with two dates 0 and 1. A risk neutral insurer is endowed with equity capital K_E and protected by limited liability. A risk averse insuree may incur a loss, normalized to 1, with probability p. Insuree losses are identically distributed, but not independent. Following Subramanian and Wang (2021), we assume that a proportion τ of insuree's losses are subject to the same aggregate shocks and perfectly correlated while the remaining proportion $1-\tau$ of insuree's losses are independent. Specifically, a proportion τ of insurees *simultaneously* experience losses with probability p, while the proportion τ do not incur losses with probability $1-p$. The remaining proportion $1-\tau$ of insurees experience independent losses. By the law of large numbers, therefore, a proportion γ^H of insurees incur losses with probability p, and a proportion $\gamma^L < \gamma^H$ incur losses with probability $1-p$, where

$$\gamma^H = \tau + (1-\tau)p; \gamma^L = (1-\tau)p \tag{1}$$

The insurer's liability portfolios inherit the correlation structure of insuree losses. Let $\widetilde{\gamma} = \{\gamma^H, \gamma^L\}$ denote the random variable of the proportion of insurees that incur losses. That is, a proportion γ^H of insurees in the insurer's pool experience losses with probability p while a proportion γ^L of insurees in the insurer's pool incur losses with probability $1-p$. By the law of large numbers, $p\gamma^H + (1-p)\gamma^L = p$. The parameter τ represents the undiversifiable *risk* in an insurer's insurance portfolio.

At date 0, the insurer sells insurance policies to insurees at price, P, per unit of insurance coverage. We assume the insurer optimally chooses insurance price, P, in a Bertrand competition facing a demand function for insurance coverage. Let $L(P)$ denote the total demand function for insurance coverage, capturing the quantity of insurance. $L(P)$ is a continuous, continuously differentiable, and strictly decreasing function of the insurance price, P. Thus, the total insurance premiums collected by the insurer is PL and the total liability of the insurer is $\widetilde{\gamma}L$ by law of large numbers.

The insurer can cede some premiums to shadow reinsurers that are defined as affiliated, unauthorized, and unrated entities. Shadow reinsurers are not subject to risk-based capital requirements and we follow Koijen and Yogo (2016) to assume that shadow reinsurers do not hold any equity capital[8] and invest all premiums assumed in the risky assets for higher expected returns. The operating insurer cedes her insurance coverage, S, to shadow reinsurer and the total premium ceded is PS. However, the increased use of shadow insurance could increase the chance of regulatory scrutiny or intervention (NYDFS, 2013; Koijen and Yogo, 2016).[9] In our one-period model, we simplify the regulatory friction cost by assuming a continuous, increasing, and convex function of the shadow insurance use, S, in the quadratic form, that is, $C(S) = \frac{1}{2}bS^2$,where $C(S) > 0$, $C'(S)$>0, $C''(S)$>0, and b is the coefficient of marginal cost of shadow insurance use.

The insurer then chooses her portfolio of investments between the risk-free asset and risky asset. The return on risk-free asset is normalized to 1. Let $\widetilde{R} = \{R^H, 0\}$ denote the random variable of gross return on risky asset, which generates $R^H > 1$ with probability, $1-q$, and

[8]Based on the available financial statement information of eight captives released by Iowa Insurance Division, six of them have essentially negative equity under SAP (Koijen and Yogo, 2016).

[9]Koijen and Yogo (2016) model the regulatory friction cost as a decreasing and convex function of leverage ratio (i.e., the ratio of statutory capital to lagged liabilities) of both operating insurer and shadow reinsurers in an infinite-horizon framework. In their model, the higher amount of insurance liability ceded to shadow reinsurers reduces statutory capital held by the operating insurer, thereby increasing the likelihood of regulatory scrutiny or intervention and the regulatory friction cost.

loses all investment principal with probability, q. The expected return on the risky asset is greater than that on the risk-free asset, $(1-q)R^H > 1$. Let X_r and X_s denote the total investments in risky and risk-free assets by the insurer, respectively. Insurers *cannot commit* to their investment choices when they sell insurance policies, so the insurance contract cannot be explicitly contingent on the insurer's investments (e.g., Subramanian and Wang, 2021). Therefore, insurers make the investment decisions by rationally incorporating their insurance price and shadow insurance decisions.

The balance sheet equation implies that the insurance premium net of shadow insurance, $P(L-S)$, and the initial equity endowment, K_E, must equal to the total invested assets (i.e., the sum of risky and risk-free assets).

$$\overbrace{X_r + X_s}^{\text{Total Investment}} = \overbrace{P(L-S) + K_E}^{\text{Insurance Premium (Net of Shadow Insurance Premium Ceded) and Equity Capital}} \tag{2}$$

The total risky asset investment by the operating insurer and by her shadow reinsurer is $X_r + PS$. Further, only the operating insurer invests in risk-free assets, the budget balance condition (2) implies that the investment in the risk-free asset is $P(L-S) + K_E - X_r$. The shadow reinsurer is also protected by limited liability and defaults when her risky asset fails. We assume there exists a common aggregate shock to all the risky assets in the economy so the payoffs of risky assets invested by the insurer and her shadow reinsurer are perfectly correlated and they would default simultaneously (Subramanian and Wang, 2021).[10] The operating insurer ultimately bears all the risk ceded to shadow reinsurer and collects all investment returns of shadow reinsurer, and defaults when total asset returns from risky asset, $(X_r + PS)\widetilde{R}$, and from risk-free asset, $(P(L-S) + K_E - X_r)$, are less than the total insurance liability, $\widetilde{\gamma}L$.

Regulator requires the insurer to hold a minimum amount of equity capital relative to

[10]We incorporate the common aggregate shocks to the risky assets invested by both insurers and their shadow reinsurers in our model. We could vary the degree of common aggregate shocks such that the risky asset returns of insurers and shadow reinsurers are independent or partially correlated. Our results are robust as long as the insurer is solvent when their shadow reinsurer's risky asset succeeds.

the amount of risky asset investment, X_r and total insurance liability, L. Thus the capital requirement of the operating insurer is expressed as follows.

$$K_E \geq \delta X_r + \theta L, \tag{3}$$

where the minimum amount of equity capital is δ times of the amount of risky asset investment, X_r and θ times of the total liability. Analogous to risk-based capital requirement, $\delta \in (0, 1]$ is the sensitivity of the minimum capital requirement to the insurer's risky assets while $\theta \in (0, 1]$ is the sensitivity of the minimum capital requirement to the insurer's underwriting risk. The violation of the capital requirement can lead to a sufficiently large penalty so that violating the capital requirement is suboptimal for the insurer. Insurers will incur additional cost if they hold excess equity capital above the minimum required capital due to the positive cost of equity[11]. We use ω to denote the cost of excess equity capital and the total additional cost excess capital is $\omega(K_E - \delta X_r - \theta L)$[12]

At date 1, the asset returns and liability payoffs are realized. We assume the insurer defaults in the states where if total investment return is low $X_r R^L + X_s$ and/or the total insurance loss claims are $\gamma^H L$. In other words, insurers may only succeed in the state when investment return is high and total insurance loss claims is low with probabiliy $(1-p)(1-q)$ [13].

Given that insurers *cannot commit* to their investment choices when they sell insurance policies, the insurers make the investment decisions by rationally incorporating their insurance price and shadow insurance decisions. We now derive insurer's decisions backward.

The insurer chooses the optimal investment in risky asset, X_r, for given insurance price, P,

[11] Holding minimum required capital is also costly, which is, however, sunk costs as violating the capital requirement is assumed to be always suboptimal.

[12] The cost of shadow insurance, $C(S)$, and the cost of excess capital and insurance acquisition, $\omega(K_E - \delta X_r - \theta L)$, are both endogenously determined in the equilibrium.

[13] We make this assumption for expositional convenience. Our results still hold if we could allow insurers not default in other states.

and shadow insurance use, S. The insurer's optimal investment decision solves the following:

$$X_r^* = \arg\max_{\{X_r|P,S\}} \mathbb{E}\left[\overbrace{(X_r + PS)\widetilde{R}}^{\text{Gross Return on Risky Asset}} + \overbrace{(P(L-S) + K_E - X_r)}^{\text{Gross Return on Risk-Free Asset}} - \overbrace{\widetilde{\gamma}L}^{\text{Insurance Loss}} \right]^+$$

$$- \overbrace{\omega(K_E - \delta X_r - \theta L)}^{\text{Costs of Excess Capital}} \cdot 1_{\{K_E > \delta X_r - \theta L\}} - \overbrace{C(S)}^{\text{Cost of Shadow Insurance}} \quad \text{subject to}$$

$$K_E \geq \delta X_r + \theta L(P)$$

For given insurance price, P, and shadow insurance use, S, the above problem is an increasing and linear function of risky asset, X_r. Thus, the risk-based capital requirement must be binding and it is optimal to invest in risky asset $X_r^* = \frac{K_E - \theta L}{\delta}$.

Insurers then make their insurance portfolio decisions–insurance price, P, and shadow insurance use S by solving the following:.

$$(P^*, S^*) = \arg\max_{\{P,S|X_r^*\}} \mathbb{E}\left[\overbrace{(X_r^* + PS)\widetilde{R}}^{\text{Gross Return on Risky Asset}} + \overbrace{(P(L-S) + K_E - X_r^*)}^{\text{Gross Return on Risk-Free Asset}} - \overbrace{\widetilde{\gamma}L}^{\text{Insurance Loss}} \right]^+$$

$$- \overbrace{\omega(K_E - \delta X_r^* - \theta L)}^{\text{Costs of Excess Capital}} \cdot 1_{\{K_E > \delta X_r^* - \theta L\}} - \overbrace{C(S)}^{\text{Cost of Shadow Insurance}} \quad \text{subject to}$$

$$K_E \geq \delta X_r^* + \theta L(P)$$

The following lemma summarizes the equilibrium.

Lemma 1 (Basic Model Equilibrium)**.** *The optimal risky asset investment, insurance price,* *and the amount of shadow insurance use satisfy the following conditions*

$$X_r^* = \frac{K_E - \theta L^*}{\delta} \tag{4}$$

$$P^* = \gamma^H - (R^H - 1)\left(\frac{S^*}{L'(P^*)} - \frac{\theta}{\delta}\right) - \frac{L(P^*)}{L'(P^*)} \tag{5}$$

$$C'\left(S^*\right) = (1-p)(1-q)P^*(R^H - 1) \tag{6}$$

3.2 Extended Model with Group Solvency Regulation

In this subsection, we extend our model to incorporate the regulatory shock occurred at the affiliated foreign insurer (or insurance group) and to capture the cross-boarder effects of group solvency regulation of Solvency II on the insurer operated in the U.S. market. As stated in Section 2.1, Solvency II would apply capital add-on at each subsidiary within the group if it is deemed necessary. Violation of the stricter group solvency standards may lead to regulatory intervention. To capture this transmission effect, we assume the operating insurer with an affiliate in EU are facing a more stringent capital requirement

$$K_E \geq \delta X_r + \theta L + \Delta \tag{7}$$

where $\Delta > 0$ captures the standards differences between foreign group regulation and domestic regulation.

The insurer's optimal investment in risky asset, X_r, for given insurance price, P, and shadow insurance use, S, now solves

$$X_r^{**} = \arg\max_{\{X_r|P,S\}} \mathbb{E}\left[\overbrace{(X_r + PS)\widetilde{R}}^{\text{Gross Return on Risky Asset}} + \overbrace{(P(L-S) + K_E - X_r)}^{\text{Gross Return on Risk-Free Asset}} - \overbrace{\widetilde{\gamma}L}^{\text{Insurance Loss}}\right]^+ - \overbrace{\omega(K_E - \delta X_r - \theta L)}^{\text{Costs of Excess Capital}} \cdot 1_{\{K_E \geq \delta X_r^* - \theta L\}} - \overbrace{C(S)}^{\text{Cost of Shadow Insurance}} \quad \text{subject to}$$

$$K_E \geq \delta X_r + \theta L(P) + \Delta$$

By similar argument, the risk-based capital requirement must be binding and it is optimal to invest in risky asset $X_r^* = \frac{K_E - \theta L + \Delta}{\delta}$.

We now derive the optimal insurance price, and the shadow insurance use given the transmission effects of Solvency II. The insurer's optimal decisions solve the following

$$(P^{**}, S^{**}) = \arg \max_{\{X_r, P, S\}} \mathbb{E} \left(\overbrace{(X_r + PS)\widetilde{R}}^{\text{Gross Return on Risky Asset}} + \overbrace{(P(L-S) + K_E - X_r)}^{\text{Gross Return on Risk-Free Asset}} - \overbrace{\widetilde{\gamma} L}^{\text{Insurance Loss}} \right)^+ - \overbrace{\omega(K_E - \delta X_r - \theta L)}^{\text{Cost of Excess Capital}} \cdot 1_{\{K_E > \delta X_r^* - \theta L\}} - \overbrace{C(S)}^{\text{Cost of Shadow Insurance}} \quad \text{subject to}$$

$$K_E \geq \delta X_r + \theta L(P) + \Delta$$

The following lemma summarizes the equilibrium in the extended model.

Lemma 2 (Extended Model Equilibrium)**.** *The optimal risky asset investment, insurance price, and the amount of shadow insurance satisfy*

$$X_r^{**} = \frac{K_E - \theta L^{**} - \Delta}{\delta} \tag{8}$$

$$P^{**} = \gamma^H + \frac{\omega\theta}{(1-p)(1-q)} - (R^H - 1)\left(\frac{S^{**}}{L'(P^{**})} - \frac{\theta}{\delta}\right) - \frac{L(P^{**})}{L'(P^{**})} \tag{9}$$

$$C'(S^{**}) = (1-p)(1-q)P^{**}(R^H - 1) \tag{10}$$

3.3 Impact of Foreign Solvency Regulation and Hypotheses

The following proposition compares the equilibria of the basic model and the extended model, and provides the implications of Solvency II's impact on the U.S. insurance market.

Proposition 1 (Impact of Foreign Solvency Regualtion)**.** *Comparing to insurers not affiliate to a foreign insurance group, suppose the insurance demand sensitivity to insurance price* *weakly increases with insurance price, the insurance demand is a weakly convex function of insurance price, the regulation difference is higher than a threshold $\widetilde{\Delta}$, the foreign affiliated insurer*

1. *invests less in risky assets;*
2. *charges higher insurance price;*
3. *uses more shadow insurance;*
4. *reduces the underwriting risk.*

Solvency II imposes an additional and stricter capital requirements on EU affiliated insurers through the transmission effects. It implies that the capital requirement Equations (3) is not binding and insurers must hold excess capital Δ to satisfy the group solvency regulation requirement. As the operating insurers hold sufficient capital, we have the first hypothesis,

- *H1: EU affiliated insurers improve their financial strength relative to the U.S. domestic insurers after the Solvency II reform.*

The increased the excess capital, in turn, increases insurance price given that the insurance demand sensitivity to insurance price weakly increases with insurance price and the insurance demand is weakly convex in insurance price. Thus the total insurance liability insured by insurers decreases given the inverse relationship between insurance price and demand. Equations (4) and (8) imply that $X_r^{**} - X_r^{*} = \frac{\theta(L^{*} - L^{**}) - \Delta}{\delta}$. We assume the differences between foreign group regulation and domestic regulation, Δ , is larger than a threshold $\widetilde{\Delta}$ as defined in Appendix A, the operating insurers with a foreign affiliate hold less risky assets. As we discuss later in the section, insurers use more shadow insurance, $S^{**} > S^{*}$, the total insurance risk left on insurer's balance sheet $L^{**} - S^{**}$ is greater than that of insurers without group solvency regulation, $L^{*} - S^{*}$. In the context of the Solvency II reform, part 1 and 4 of Proposition 1 implies that

- *H2: EU affiliated insurers improve their financial strength through reduced asset risk and reduced underwriting risk.*

The equilibrium shadow insurance use is determined when the marginal cost of shadow insurance use, bS^{**}, equals to its marginal benefit $P^{**}q(R^H - 1)$. An increase in the insurance price after Solvency II increases the marginal benefit of shadow insurance use because more shadow insurance premium ceded can be invested in risky assets. Thus, insurers will further increase the shadow insurance use after Solvency II to maximize its expected profit. Further, because shadow reinsurers are less regulated and unrated, they can take more risk for given amount of capital than regular insurers. A more stringent solvency regulatory reform, like the Solvency II reform, may thus motivate increasing use of shadow insurance. EU affiliated insurers can use shadow insurance to get around the higher costs driven by higher capital requirement while still maintaining its financial ratings. This is consistent with the regulatory arbitrage hypothesis. Thus, part 3 of Proposition 1 implies that

- *H3: EU affiliated insurers use more shadow insurance relative to the U.S. domestic insurers after the Solvency II reform.*

The use of shadow insurance may impair the financial strength of insurers and increase insolvency risk because shadow reinsurers can take more risks than regular insurers given the same amount of capital. Shadow insurance does not actually transfer risks out of the insurance group and insurers are ultimate responsible for all business they insure. Moreover, shadow reinsurers who typically report under GAAP are not subject to RBC regulation and can fund their business using letters of credit. A.M. Best claims that their rating process has entailed the assessment of shadow insurance use, so that its ratings capture the potential risk imposed by shadow insurance. However, the existing literature argues that the potential risk arising from shadow insurance use has not been adequately reflected by financial strength ratings, given that shadow insurance and the financial statements of shadow reinsurers are unavailable to the public and rating agencies. Koijen and Yogo (2016) find that there exists no meaningful negative relation between ratings and shadow insurance use. Hepfer et al. (2020) find that shadow insurance is associated with lower liquid asset holdings and increased credit risk. We state this financial strength rating hypothesis in its null form as that

- *H4: The financial strength ratings adequately reflect the potential risk of shadow insurance use.*

The increased insolvency risk driven by the increased shadow insurance use (i.e., the regulatory arbitrage effects) may offset the improved financial strength driven by the reduced asset and underwriting risks (i.e., the regulatory transmission effects). Their combined effects remain unclear. We present this hypothesis in its null form as that

- *H5: EU affiliated insurers improve their shadow-insurance-adjusted financial strength relative to the U.S. domestic insurers after the Solvency II reform.*

4 Data

In the rest of the paper, we use the Solvency II reform as a quasi-natural experiment to test above hypotheses. We empirically examine the impact of Solvency II on the U.S. P/C insurance market by comparing the level of financial strength and the amount of risk-taking between U.S. domestic insurers and EU affiliated insurers operating in the U.S. market.

4.1 Sample

Our dataset is from the National Association of Insurance Commissioners (NAIC) InfoPro database for the period of 2006 to 2019. We collect the demographic, financial, and reinsurance transaction information of all U.S. P/C insurers at the operating firm level. We manually collect the domicile locations of their ultimate parent and their affiliated entities within the same group for each operating insurer. Therefore, we can identify insurers with or without EU affiliates to construct our key variable of interest that differentiates U.S.

domestic insurers and EU affiliated insurers. We obtain insurers' financial strength ratings from the A.M. Best database and asset return indices from the Bloomberg database.

Our sample begins in 2006, the year when the FSA group supervision proposal was published and Solvency II may subsequently have a transmission effect outside the EU. Our sample period covers the rest of the rule development phase (2006-2009), the entire implementation phase (2010-2015), and four years after the enforcement of Solvency II (2016-2019). Our sample covers insurers' possible preparation and transition period for the Solvency II reform.

We start with all P/C insurers that report the Schedule Y "Organizational Structure" to NAIC. The initial dataset includes 2,994 P/C insurers and 36,940 firm-year observations. We apply standard data screening process to generate our regression sample. Specifically, we exclude 19,538 observations with non-positive total assets, non-positive total liabilities, non-positive direct premiums earned, or with missing values in any regression variables. Finally, we exclude 116 observations for reinsurers, whose reinsurance assumed from non-affiliates is more than 75% of the sum of direct premiums written and reinsurance assumed from affiliated insurers (Cole et al., 2007). Our final sample consists of 1,717 P/C insurers and 17,286 firm-year observations.

4.2 Key Variables

We create a dummy variable *EU Affiliate* indicating whether an operating insurance company has insurance ultimate parent or insurance affiliations domiciled in the EU and are therefore subject to Solvency II regulation. *EU Affiliate* equals 1 if the operating company affiliates to or has an affiliated EU insurance entity, 0 if the operating company neither affiliates to nor has an affiliated EU insurance entity. In other words, U.S. domestic insurers are those insurers without an EU insurance affiliate.[14]

Following prior literature (Pottier and Sommer, 1999; Shim, 2010; Che and Xu, 2020),

[14]Our definition of U.S. domestic insurers also incorporate the ones with ultimate parent in the U.S. and an affiliate in a third country.

we use A.M. Best ratings to capture an insurer's financial strength and ability to meet their obligations of ongoing policies and contracts. The Financial Strength Rating incorporates an insurer's balance sheet strength, operating performance, business profile, and enterprise risk management practice (A.M. Best Company, 2020). U.S. experience suggests that rating agencies have been more successful in identifying financial distress than has the RBC standards (Eling et al., 2007). Insurers with a higher A.M. Best rating are likely to experience lower insolvency risk. We classify A.M Best ratings into three categories with an increasing order for each insurer. *AMB Rating* equals 1 if an insurer is rated C++ or below, 2 if between B- and B++, and 3 if A- or above.

Conventionally, insurers manage its insolvency risk and respond to a solvency regulatory reform by determining and adjusting their asset risk-taking, underwriting risk-taking, capital holdings, and reinsurance use, among others (Baranoff and Sager, 2002; Shim, 2010).

We measure an insurer's asset portfolio risk (*Asset Risk*) by the volatility of asset portfolio returns of each insurer in each year as shown in Formula (11) (Cummins and Sommer, 1996; Shim, 2010).

$$\mathit{Asset\ Risk} = \sqrt{\sum_{i=1}^{6}\sum_{j=1}^{6} y_i y_j \rho_{A_i A_j} \sigma_{A_i} \sigma_{A_j}} \tag{11}$$

where $y_i(y_j)$ is the fraction of asset $i(j)$ and $\rho_{A_iA_j}$ is the correlation coefficient between the log return of asset i and the log return of asset j. $\sigma_{A_i}(\sigma_{A_j})$ captures the volatility of asset $i(j)$ and is estimated using the standard deviation of industry-wide quarterly time series of returns for asset $i(j)$.[15] Note that $\rho_{A_iA_j}$, σ_{A_i}, and σ_{A_j} are the same for all insurers across all years. *Asset Risk* varies for each insurer in each year because the fraction of each asset type is different for each insurer in each year.

We measure an insurer's underwriting risk using the standard deviation of loss ratios (*SD Loss Ratio*) over the past 4-year rolling periods (Ho, Lai, and Lee, 2013). We omit *SD*

[15] The quarterly returns of each asset type are estimated based on the following indices: the Standard & Poor's 500 index for stocks, Intermediate Government/Credit Bond ETF index for Government bonds, Moody's corporate bond index for corporate bonds, MSCI US REIT index for real estate, the S&P U.S. Mortgage-Backed Securities index for mortgages, and 30 days US Treasury bill rate for cash and other invested assets.

Loss Ratio values over the period from 2010 to 2012 to avoid the correlations of *SD Loss Ratio* around the event year of 2010. We measure an insurer's *Capital Holding* by capital divided by total liability (Koijen and Yogo, 2016). Insurers manage its underwriting risks also by ceding premiums to reinsurers. We therefore use *Unaffiliated Reinsurance* to capture an insurer's "real" underwriting risk transfer to entities outside its group, defined as net reinsurance ceded to unaffiliated reinsurers divided by total premiums earned (Fier et al., 2013).

Following Koijen and Yogo (2016), we define reinsurers that are affiliated, unauthorized and A.M. Best unrated as shadow reinsurers. We measure the amount of *Shadow Insurance* use by the ratio of total premiums ceded to shadow reinsurers to the total reinsurance premiums ceded. We also create a dummy variable *Shadow Insurance Use,* which equals 1 if the premiums ceded to shadow reinsurers is positive and 0 otherwise.

Complementing the identification of shadow insurance by Koijen and Yogo (2016), we manually check the domiciled location of each reinsurers of the shadow insurance and categorize them into EU, U.S. and third markets. We create three variables *Shadow Insurance to EU* , *Shadow Insurance to U.S.,* and *Shadow Insurance to Third Markets* to indicate the percentage of insurance premium ceded to shadow reinsurers based in the EU, in the U.S., and in a third market, over total premium ceded, *respectively.*

We construct the variable *Adj AMB Rating* in two steps following Koijen and Yogo (2016). First, we generate the variable *Numeric AMB Rating* by converting the AMB rating to a numeric equivalent score based on the risk-based capital guidelines (A.M. Best Company, 2011, p.24). The numeric score ranges from 175% to 0%, used by A.M. Best Company to determine the capital adequacy of an insurance company. Second, we multiply *Numeric AMB Rating* by the fraction of insurance business that are not shadow reinsured to adjust for the potential impact of shadow insurance as shown in Equation (12), and then convert the adjusted *Numeric AMB Rating* back to the categorical ratings based on the same risk-based capital guidelines. The more shadow insurance an insuer uses, the lower *Adj AMB*

Rating the insurer will have. In that sense, *Adj AMB Rating* reflects the potential impact of shadow insurance if any.

$$\begin{aligned}&\textit{Adj numeric AMB Rating} \\ &= \frac{\textit{Numeric AMB Rating} \times \left(\begin{array}{c}\textit{Gross Premium Written} \\ -\textit{Premium Ceded to Shadow Reinsurer}\end{array}\right)}{\textit{Gross Premium Written}}\end{aligned} \tag{12}$$

Table 1 provides the definition of all variables used in later regressions. Table 2 presents their summary statistics. We winsorize all continuous variables at the 1st and 99th percentiles to diminish potential bias driven by the extreme values (except for *Shadow Insurance* because many observations have the value of zero).

5 Empirical Methodology

5.1 Transmission Effects through Conventional Channels

To test H1, we employ a difference-in-difference (DID) approach (Bertrand and Mullainathan, 2003; Bertrand et al., 2004) to investigate the impact of the Solvency II reform on insurers' overall financial strength (insolvency risk). The treated firms are the EU affiliated insurers that are potentially subject to the regulatory changes of the Solvency II reform. The control firms are the U.S. domestic insurers that are not subject to the regulation of Solvency II. Our basic empirical design entails estimating Equation (13) below with ordered logit regression to investigate whether EU affiliated insurers have significantly different changes in financial strength (insolvency risk) from U.S. domestic insurers after the event year of Solvency II.

$$AMB\ Rating_{it} = \beta_0 + \beta_1 EU\ Affiliate_{it} + \beta_2 EU\ Affiliate_{it} \times Post_{it} + \beta_3' X_{it}$$
$$+ \beta_4' Year_t + \beta_5' State_i + \varepsilon_{it} \tag{13}$$

$AMB\ Rating_{it}$ captures the financial strength of each insurer i at the end of year t. $EU\ Affiliate_{it}$ is a dummy variable that equals 1 if the firm is an EU affiliated insurer and equals 0 if the firm is a U.S domestic insurer in year t. X_{it} is a vector of firm-level control variables including firm size (*Size*), geographic diversification (*Geographic HHI*), line of business diversification (*Business HHI*), loss ratio (*Loss Ratio*), returns on assets (*ROA*), organizational form (*Mutual*), and asset growth (*Asset Growth*).

We define *Post* as a dummy variable that equals 1 for the event year of Solvency II reform, 2010, and thereafter, and 0 otherwise. The interaction term of $EU\ Affiliate_{it}$ and $Post_{it}$ is our DID estimator. Its coefficient β_2 captures the average difference before and after the Solvency II event year, in the difference of the overall insolvency risk between EU affiliated insurers and U.S. domestic insurers. A positive β_2 supports H1 and is consistent with the regulatory transmission hypothesis, where the stringent regulation and prudent business practice in the EU insurance market spill over to the U.S. insurance market. In contrast, a negative β_2 rejects *H1* and is consistent with the regulatory arbitrage hypothesis, where risks are transferred from markets with more stringent capital requirements to markets with less stringent requirements.

We include the year fixed effects ($Year_t$) in the regression to account for the uncontrollable time-varying factors and state fixed effects ($State_i$) to purge out the unobservable time invariant state-level factors (e.g., state regulation, culture, and traditions). We do not control for the firm fixed effects because the status of EU affiliation, for most insurers, is time-invariant, which would be perfectly correlated with the firm fixed effects. We do not use the state-year fixed effect as the state-level regulation did not change over the past 20 years for most states. The standard errors are clustered at the firm level to account for uncontrollable heterogeneities between insurers.

The validity of the DID approach builds on the parallel trend assumption, that is the insolvency risk of the treated and control firms would move in parallel in the absence of the Solvency II reform. In other words, there should preferably not be any pre-trend of differences in the insolvency risks between EU affiliated insurers and U.S. domestic insurers before the Solvency II event year. To clearly establish the parallel trend, we in addition estimate a model that specifically captures the difference between the treatment and control firms in *AMB Rating* by year (Frakes, 2013; Che and Xu, 2020). Specifically, we add the interaction terms of $\textit{EU Affiliate}_{it} \times Year_{T+j}$ to identify how $\textit{AMB Rating}_{it}$ changed around the event year T for EU affiliated insurers relative to U.S. domestic insurers. The first year of our sample (i.e., 2006 or $T-4$) is used as the base year and therefore omitted from the regression. To make the event window balanced around the event year of T, we bin T+4 and subsequent years by creating the dummy variable $Year_{T+4\&after}$ for years of 2014 and onwards. Our model is thus as follow:

$$\begin{aligned} \textit{AMB Rating}_{it} &= \beta_0 + \beta_1 \textit{EU Affiliate}_{it} + \sum_{j=-3}^{3} \gamma_j \textit{EU Affiliate}_{it} \times Year_{T+j} \\ &+ \gamma_4 \textit{EU Affiliate}_{it} \times Year_{T+4\&after} + \beta_3' X_{it} + \beta_4' Year_t + \beta_5' State_i + \varepsilon_{it} \end{aligned} \tag{14}$$

We further examine the channels, through which EU affiliate insurers improve their financial strength. As we discussed in Section 2, the conventional channels ($Channel_{it}$) in response to a regulatory reform include the adjustment of asset and underwriting risk-taking (H2), the adjustment of capital holdings, and the use of reinsurance. We thus estimate Equation (15) with OLS to investigate whether EU affiliated insurers have significantly different changes in *Asset Risk*, *Underwriting Risk*, *Capital Holding*, and/or *Unaffiliated Reinsurance* use from U.S. domestic insurers after the Solvency II event year.

$$Channel_{it} = \beta_0 + \beta_1 EU\ Affiliate_{it} + \beta_2 EU\ Affiliate_{it} \times Post_{it} + \beta_3' X_{it} + \beta_4' Year_t + \beta_5' State_i + \varepsilon_{it} \quad (15)$$

Following the rationale of the regulatory transmission hypothesis, we expect a negative β_2 for the asset risk and underwriting risk channels (i.e. *H2* holds) and a positive β_2 for the capital holding and reinsurance use channels. In other words, we expect to observe that EU affiliated insurers engage in some or all of the following activities: reducing asset and underwriting risk-taking, increasing capital holdings, and ceding more reinsurance out of its group. Alternatively, if the regulatory arbitrage hypothesis holds, we expect to observe the opposite signs of β_2 for asset risk, underwriting risk, and capital holding channels.[16]

5.2 Regulatory Arbitrage through Shadow Insurance

To test *H3*, i.e., the shadow insurance channel in response to the regulatory reform, we estimate the following equation with OLS. We control for the same firm-level variables as in Equation (13).

$$Shadow\ Insurance_{it} = \beta_0 + \beta_1 EU\ Affiliate_{it} + \beta_2 EU\ Affiliate_{it} \times Post_{it} + \beta_3' X_{it} + \beta_4' Year_t + \beta_5' State_i + \varepsilon_{it} \quad (16)$$

The coefficient β_2 captures the difference before and after the Solvency II event year in the difference of shadow insurance use between EU affiliated insurers and U.S. domestic insurers. A positive β_2 supports *H3* where more risks are transferred to shadow reinsurers by EU affiliated insurers. In contrast, a negative β_2 rejects *H3* and implies that EU affiliated

[16]A negative β_2 in the Unaffiliated Reinsurance regression would indicate that EU affiliated insurers cede less to unaffiliated reinsurance firms on a net basis compared to U.S. domestic insurers, which is not related to the regulatory arbitrage hypothesis.

insurers do not increase their use of shadow insurance to circumvent the more stringent Solvency II.

Similarly, we examine the parallel trend assumption, that is whether the difference between the use of shadow insurance by EU affiliated insurers (the treated firms) and U.S. domestic insurers (the controlled firms) would move in parallel before the Solvency II reform. We estimate the model as follows.

$$\text{Shadow Insurance}_{it} = \beta_0 + \beta_1 EU\ Affiliate_{it} + \sum_{j=-3}^{3} \gamma_j EU\ Affiliate_{it} \times Year_{T+j} + \gamma_4 EU\ Affiliate_{it} \times Year_{T+4\&after} + \beta_3' X_{it} + \beta_4' Year_t + \beta_5' State_i + \varepsilon_{it} \quad (17)$$

To test *H4*, we estimate the following equations with ordered logit model to investigate whether AMB Rating and the shadow-insurance-adjusted AMB Rating change with the amount of shadow insurance use. Z_{it} is a vector of control variables that are used in the A.M. Best rating process.

$$AMB\ Rating_{it} = \beta_0 + \beta_1 Shadow\ Insurance_{it} + \beta_2' Z_{it} + \beta_3' Year_t + \beta_4' State_i + \varepsilon_{it} \quad (18)$$

$$Adj\ AMB\ Rating_{it} = \beta_0 + \beta_1 Shadow\ Insurance_{it} + \beta_2' Z_{it} + \beta_3' Year_t + \beta_4' State_i + \varepsilon_{it} \quad (19)$$

The coefficient β_1 captures the impact of shadow insurance use on insurers' (adjusted) financial strength rating. A positive β_1 in Equation (18) supports *H4*. A positive β_1 in Equation (19) and an insignificant β_1 in Equation (18) reject *H4* and suggest that the AMB financial strength rating does not adequately reflect the risks arising from the shadow insurance use, which is however captured by the Adj AMB rating.

To test *H5*, we employ again the DID approach and re-estimate Equation (13) using Adj AMB Rating as the dependent variable . The coefficient β_2 of $EU\ Affiliate_{it} \times Post_{it}$ captures the difference before and after Solvency II event year in the difference of shadow-insurance-adjusted "real" financial strength between EU affiliated insurers and U.S. domestic insurers.

A positive β_2 supports *H5* that is the "real" financial strength of EU affiliated insurers increases relative to the U.S. domestic insurers after the event year of Solvency II. In other words, the regulatory transmission effects dominate the regulatory arbitrage effects of shadow insurance. In contrast, a negative β_2 rejects *H5,* suggesting that the regulatory arbitrage effects of shadow insurance dominate the the regulatory transmission effects. An insignificant β_2 suggests that the effects of regulatory transmission and regulatory arbitrage offset each other. To complement the DID approach, we also re-estimate Equation (14) using Adj AMB Rating as the dependent variable to examine whether the parallel trend assumption holds.

To examine whether it is the shadow insurance use that weakens the "real" financial strength of EU affiliated insurers and erodes the regulatory transmission effects of Solvency II, we estimate Equation (20) below.

$$\begin{aligned}
&Adj\ AMB\ Rating_{it} = \beta_0 + \beta_1 EU\ Affiliate_{it} + \beta_2 EU\ Affiliate_{it} \times Post_{it} + \beta_3 EU\ Affiliate_{it} \\
&\times Shadow\ Insurance\ Use_{it} + \beta_4 EU\ Affiliate_{it} \times Post_{it} \times Shadow\ Insurance\ Use_{it} \\
&+ \beta_5 Shadow\ Insurance\ Use_{it} + \beta_6 Shadow\ Insurance\ Use_{it} \times Post_{it} \\
&+ \beta_7' X_{it} + \beta_8' Year_t + \beta_9' State_i + \varepsilon_{it} \qquad (20)
\end{aligned}$$

A positive β_2 suggests that the regulatory transmission effects of Solvency II exist among insurers not using shadow insurance, and a negative β_4 indicates that the regulatory arbitrage effects of shadow insurance erodes the transmission effects if any. The variance inflation factors (VIF) in all regressions are below 10, indicating that multicollinearity is not a concern.

6 Results

6.1 Regulatory Transmission through Conventional Channels

Table 3 shows the impact of the Solvency II reform on firms' financial strength in the U.S. P/C insurance market. We introduce the interaction terms step by step. In Column (1), the positive coefficient of *EU Affiliate* suggests that the *AMB Rating* for EU affiliated insurers is on average higher than that for U.S. domestic insurers over the entire sample period. The DID results in Column (2) show positive coefficients of *EU Affiliate* and *EU Affiliate* $\times$ *Post*, suggesting that, before the event year of 2010, the *AMB Rating* of EU affiliated insurers (i.e., the treated group) had been higher than that of U.S. domestic insurers (i.e., the control group) and, in the event year of 2010 and after, the average financial strength difference between the treated and control groups further increases. In other words, the financial strength gap between EU affiliated insurers and U.S. domestic insurers becomes larger after the Solvency II reform. Our DID results are consistent with the regulatory transmission hypothesis and supports H1 in the sense that the prudent business practice as a result of Solvency II reform spills over to the U.S. insurance market.

Columns (3) in Table 3 reports the dynamic trend of the differences in financial strength between EU affiliated and U.S. domestic insurers, which is consistent with the DID results in Column (2). The positive coefficient of *EU Affiliate* suggests that in the base year of 2006, the *AMB Rating* of EU affiliated insurers had already been higher than that of U.S. domestic insurers. Importantly, the coefficients of $\textit{EU Affiliate}_{it} \times Year_{T+j}$ are insignificant when $j < 0$, suggesting no pre-trend of differences in financial strength between EU affiliated and U.S. domestic insurers before the Solvency II event year of 2010. In other words, the difference in financial strength between the two groups of insurers does not change before the event year. In contrast, the coefficients of $\textit{EU Affiliate}_{it} \times Year_{T+j}$ become positive for all $j \geq 0$. It implies that the differences in *AMB Rating* between EU affiliated and U.S. domestic insurers increase, relative to the years of 2006-2009, starting from the Solvency II event year of 2010. Further, the increased difference in *AMB Rating* remains stable for all subsequent years of 2010-2019. The Wald test suggests that the coefficients of $\textit{EU Affiliate}_{it} \times Year_{T+j}$ for all $j \geq 0$ are not significantly different from each other with p-value=0.803. Regarding the control variables, the financial strength ratings increase with firm size, profitability, and growth, and decrease with geographic diversification and loss ratio.

We plot the parallel trend based on the results in Column (3), Table 3. Figure 1 displays the estimated coefficients with 90% confidence intervals of the interaction terms of $EU\ Affiliate_{it} \times Year_{T+j}$. In 2006-2009, the difference in the *AMB Rating* between EU affiliated insurers and U.S. domestic insurers is stable and hovers close to the zero line, indicating that the financial strength of our treated and control groups moves in a parallel pattern. In the event year of 2010, we observe a structural increase in the difference in financial strength between these two groups and the difference stays stable above the zero line and above the pre-event levels in subsequent years. This pattern suggests that the Solvency II reform increases the financial strength of EU affiliated insurers relative to U.S. domestic insurers. Figure 1 supports the parallel trend assumption of our DID approach. Taken together, our results support the existence of regulatory transmission effects in the sense that EU affiliated insurers improved their financial strength in the Solvency II event year of 2010, when they are able to quantitatively estimate the real impact of the Solvency II reform according to Directive 2009/28/CE and QIS5.

Table 4 shows the channels, through which EU affiliated insurers improve their financial strength after the Solvency II reform. The results for the asset risk adjustment channel are shown in Columns (1) and (2). The negative coefficient of *EU Affiliate* in Column (1) implies that the asset risk-taking of EU affiliated insurers is on average lower than that of U.S. domestic insurers over the entire sample period. In Column (2), the coefficient of *EU Affiliate* becomes insignificant, while the coefficient of the interaction term *EU Affiliate* $\times$ *Post* is negative. The results imply that there be no significant difference in asset risk-taking between EU affiliated and U.S. domestic insurers before the event year of 2010, but the difference becomes significant in 2010 and onwards. In other words, EU affiliated insurers decrease asset risk-taking relative to U.S. domestic insurers since the Solvency II event year of 2010. The underwriting risk adjustment results are shown in Columns (4) and (5). The positive coefficient of *EU Affiliate* in Column (4) indicates that the average underwriting risk of EU affiliated insurers is greater than U.S. domestic insurers over the whole sample period. In Column (5), the coefficient of *EU Affiliate* remains positive and the coefficient of *EU Affiliate* × *Post* is negative. The results imply that EU affiliated insurers hold greater underwriting risk than U.S. domestic insurers before the Solvency II event year, but the difference in underwriting risk between the two groups of insurers decreases since the event year. The results in Table 4 support H2 and are consistent with the regulatory transmission hypothesis, suggesting that the asset and underwriting risk-taking be important channels contributing to the reduced insolvency risk (i.e., improved financial strength) of EU affiliated insurers. The results of the dynamic parallel trend of the differences are shown in Columns (3) and (6), which are consistent with our DID results. The additional results in Table A1 in Appendix B, however, show that the changes in capital issuance and reinsurance use are insignificant after the Solvency II reform. This may be due to the fact that it is more expensive to raise external equity according to the Pecking Order Theory and given the financial market frictions (Mayer and Majluf, 1984). Besides, there are also many regulation restrictions for capital transactions within an insurance group. For example, the insurers must notify the regulators about the plan of material capital transactions with affiliates and the state regulators are authorized to prevent such transactions if necessary (Niehaus, 2018). The unaffiliated reinsurance may be less attractive as it does not only transfer insurance risks but also expected profits to unaffiliated reinsurers.

6.2 Regulatory Arbitrage through Shadow Insurance

Table 5 shows the impact of the Solvency II reform on insurers' amount of shadow insurance use. The positive coefficient of *EU Affiliate* in Column (1) implies that EU affiliated insurers, on average, use more shadow insurance than U.S. domestic insurers over the entire sample period. The DID results in Column (2) show an insignificant coefficient of *EU Affiliate* and a positive coefficient of *EU Affiliate* × *Post*. The results indicate that there be no difference in the use of shadow insurance between EU affiliated insurers and U.S. domestic insurers before the Solvency II event year of 2010, but the difference becomes significant after 2010. In other words, EU affiliated insurers cede 1.55 percentage points more of their insurance business to the shadow reinsurers out of the total premium ceded compared to U.S. domestic insurers after the Solvency II reform, which is equivalant to 23% increase of the shadow insurance use (on average, the premium ceded to shadow reinsurers to total premiums ceded is 6.72%).

The dynamic trend of the differences in shadow insurance use in Column (3) is consistent with the DID results in Column (2). The coefficients of $\textit{EU Affiliate}_{it} \times Year_{T+j}$ are insignificant when $j \leq 0$, suggesting no pre-trend of differences in the use of shadow insurance between EU affiliated and U.S. domestic insurers. In contrast, the coefficients of $\textit{EU Affiliate}_{it} \times Year_{T+j}$ become significantly positive for all $j > 0$, implying that the differences in shadow insurance use between these two groups of insurers increase relative to the base years.We plot the dynamic parallel trend in Figure 2. In 2006-2010, the difference in the use of shadow insurance between EU affiliated insurers and U.S. domestic insurers lies stably close to the zero line, indicating that the shadow insurance use of the treated and control groups moves in a parallel pattern. Since 2011, we observe a structural increase in the difference in shadow insurance use between these two groups and the difference stays above the zero line and above the pre-event levels in subsequent years. The results support *H3* in the sense that EU affiliated insurers increase their shadow insurance use relative to the U.S. domestic insurers after the Solvency II reform.[17]

We further investigate the impact of Solvency II on cross-market risk transfers by examining the amount of shadow insurance ceded to different markets. We estimate Equation (16) with dependent variables of *Shadow Insurance to EU, Shadow Insurance to U.S.,* and *Shadow Insurance to Third Markets,* respectively. The results in Columns (4)-(6) of Table 5 suggest that EU affiliated insurers cede more business to shadow reinsurers domiciled in the third markets (but not to those domiciled in the U.S. or EU) compared to U.S. domestic insurers after the Solvency II reform. 94.6% premiums ceded to shadow reinsurers in third

[17]We note that the structural change in shadow insurance use happened in 2011, one year after the event year of 2010. This is because the reinsurance programs in the U.S. P/C market are typically renewed in June 1st or July 1st, but the QIS5 was released in July 5, 2010. Therefore, it was not until June or July of 2011 that EU affiliated insurers can effectively adjust their reinsurance arrangements.

markets are ceded to offshore markets that are Bermuda, Cayman Islands, Panama, Turks and Caicos Islands, and Liechtenstein, which have less strict solvency regulations and are in the shadow of Solvency II and RBC regulations.

Table 6 shows the impact of the shadow insurance use on the original (Panel A) and adjusted (Panel B) A.M. Best ratings. We use two alternative sets of control variables: (i) X_{it}, as defined in Equation (13) in Columns (1) and (3); (ii) Z_{it} in Columns (2) and (4), including *ROE*, *Size*, *Log Liabilities*, *Capital Holding*, *RBC Ratio*, and *Stock Company* following Koijen and Yogo (2016). The coefficients of *Shadow Insurance* in the original *AMB Rating* regressions (Panel A) are insignificant, indicating that A.M. Best ratings do *not* adequately reflect the potential risk arising from shadow insurance use. The coefficients of *Shadow Insurance* in the *Adj AMB Rating* regressions (Panel B) are negative, indicating that the *Adj AMB Rating* successfully captures the potential risk arising from the shadow insurance use. Our results thus reject *H4* and are consistent with the findings in the life insurance industry (Koijen and Yogo, 2016; Hepfer et al., 2020).

6.3 Combined Effects of Regulatory Transmission and Arbitrage

Table 7 shows the impact of the Solvency II reform on firms' shadow-insurance-adjusted financial strength. Similar to the results in Table 3, the coefficients of *EU Affiliate* remain positive, indicating that EU affiliated insurers have higher adjusted AMB ratings than U.S. domestic insurers on average over the sample period (Column (1)), before the Solvency II reform (Columns (2) and (4)), and in the base year of 2006 (Column (3)). The coefficients of the interaction terms *EU Affiliate* × *Post* in Column (2) and $\textit{EU Affiliate}_{it} \times Year_{T+j}$ in Column (3) become insignificant, suggesting no significant impact of the Solvency II reform on the financial strength of EU affiliated insurers after considering the regulatory arbitrage effects of shadow insurance use. The parallel trend in Figure 3 also show no structural change in the differences of *Adj AMB Rating* between these two groups of insurers over the whole sample period.

In Column (4) of Table 7, we further include the triple interaction term of *EU Affiliate*× *Post*×*Shadow Insurance Use*. Its negative coefficient implies that compared to firms not using shadow insurance, EU affiliated insurers using shadow insurance decreases their adjusted "real" financial strength relative to U.S. domestic insurers after the Solvency II reform. In other words, the regulatory arbitrage effects of Solvency II are driven by insurers using shadow insurance. Meanwhile, the coefficient of *EU Affiliate*×*Post* is positive, suggesting that the regulatory transmission effects of Solvency II are driven by insurers not using shadow insurance. We note that the negative coefficient of the triple interaction term (-0.9909) and the positive coefficient of *EU Affiliate*×*Post* (0.9017) are close in magnitude, suggesting that risk-increasing effect of shadow insurance use is likely to completely offset the risk-reduction effect of Solvency II transmission for EU affiliated insurers that use the shadow insurance. In other words, the "true" insolvency risk of EU affiliated insurers was only reduced for those not using shadow insurance but was not for those using shadow insurance. The coefficients of *Shadow Insurance Use* and *EU Affiliate*× *Shadow Insurance Use*. Our results reject *H5*.

Our results together indicate that the improved financial strength in appearance measured by *AMB rating* comes from the reduced asset and underwriting risk. However, as the risk of shadow insurance use is not adequately captured by the rating, the seemingly improved financial strength disappears after taking into account the risk of shadow insurance. In this sense, the regulatory arbitrage through the use of shadow insurance erodes the transmission effect of Solvency II.[18]

6.4 Alternative Explanations and Additional Tests

To exclude the possibilities of alterantive explanations, we conduct the following tests and the results are documented in Appendix B.

[18]Therefore, the EU affiliates can either be less or more competitive compared with U.S. domestic. On the one hand, EU affiliates may be less competitive due to the cost of more stringent regulation. But on the other hand, EU affiliates may be more attractive for the customers as a results of higher AM Best rating and the EU affiliates also reduce the cost of meeting regulation requirement by using shadow insurance, both making them more competitive.

The first concern is whether the reduced insolvency risk of EU affiliated insurers is driven by their insufficient capital position before the Solvency II reform. In other words, their reduced insolvency risk is because they were too risky and now they return to the safety level of U.S. domestic insurers. We can exclude this possibility by observing the positive coefficients of *EU Affiliate* in Columns (1) and (2) of Tables 3 and A1. The results suggest that, for the whole sample period and for the period before the event year of Solvency II reform, EU affiliated insurers always have lower insolvency risk and higher capital adequacy than U.S. domestic insurers.

Secondly, whether the year of 2010 is the appropriate event year. To verify this, we perform a standard event study. We compare two event dates when the Solvency II Directive (2009/28/CE) was published (i.e., November 25th, 2009) and when Solvency II reform was officially implemented (i.e., January 1st, 2016). We test whether the cumulative abnormal returns (CARs) of insurers around the event dates are significantly different from 0 to examine whether the respective event is a shock to the insurance industry. [19]The results are shown in Table A2. The mean CAR(-1,1), CAR(-2, 2), and CAR (-5, 5) are all negtive in Colunm (1) around the date of Solvency II Directive (2009/28/CE) release, but insignificant in Colunm (2) when Solvency II came into effect. These results support our choice of 2010 as the event year: following the Solvency II Directive, most insurance companies have already met the Solvency II capital requirements before its effectiveness in 2016 (Höring, 2013).

Thirdly, to address the reverse causality concern between AM Best rating and *EU Affiliate*, we re-estimate Equation (13) with *AMB Rating Change* and *Adj AMB Rating Change* as dependent variables. *AMB Rating Change* (*Adj AMB Rating Change*) is defined as an or-

[19]To calculate the CARs, we first measure the daily abnormal returns using the standard market model. The initial sample to estimate the market model consists of all listed insurers in countries regulated by Solvency II. We further restrict the sample to insurers which are listed before the estimation window and thus have enough observations of stock returns during the estimation window. Following Deng et al. (2013), the estimation window is defined as two hundred trading days ending 11 days before the event date, i.e., from 211 trading days to 11 trading days before the event date. For the market return required by the market model, we use the return of Financial Times Stock Exchange 100 Index as a proxy. Then the daily abnormal stock returns estimated from the market model are cumulated to obtain the CAR from day t_1 before the event date to day t_2 after the event date, denoted as CAR(-t_1, t_2).

dered categorical variable that equals -1 if *AMB Rating* (*Adj AMB Rating*) is downgraded from the previous year, 0 if it does not change, and 1 if it is upgraded. The results in Table A3 show that the coefficient of *EU Affiliate* × *Post* in Column (2) is positive and becomes insignificant in Column (4), suggesting that the A.M. Best ratings of EU affiliated insurers are upgraded compared with U.S. domestic insurers after the Solvency II reform.

Fourthly, as the event year of 2010 is close to the 2008 finaicial crisis, one may concern the differences between EU affiliated insurers and U.S. domestic insurers are driven by the finaicial crisis. To address this concen, we consider a placebo event in 2008. Specfically, we replace *EU Affiliate* × *Post* with *EU Affiliate* × *Placebo Post* in the regressions, and exclude observations after 2010 to avoid the influence of Solvency II reform. Table A4 shows insignificant coefficients of *EU Affiliate* × *Placebo Post* , suggesting that the 2008 finaicial crisis cannot explain the difference between EU affiliated insurers and U.S. domestic insurers. The results using 2007 as the placebo event year are similar to those of 2008 and available from the authors upon request. With respect to the COVID-19 crisis, although in the very late of 2019 (December 12th) we started to notice the existence of COVID-19, it is until Februry, 2020 cases of COVID-19 begin to multiply around the world and in March, 2020 the WHO characterizes COVID-19 as a pandemic. In this sense, our results using the sample in 2006-2019 are unlikely influenced by the COVID-19 crisis, which basicly started in 2020 .

Fifthly, to check whetherour results are random noises, we randomly assign the same percentage of companies as EU affiliate insurers and re-estimate Equations (13) and (16). We repeat the procedure 500 times. Table A5 reports the average t-value of the 500 regressions. The percentiles of the sampling distribution, below which the actual t-value in our main regression lies, are smaller than 0.01, suggesting that our results are not random noises in 99% confidence.

Sixthly, to check the potential influence of the regulaion in a third country, we further condutct a robustness test by excluding observations for insurers with ultimate parents or affiliated insurers in a third country other than EU and the U.S., to rule out the potential influence of a third country's regulatory system. The results shown in Table A6 are consistent with our main results.

Lastly, we investigate Solvency II's impact on different types of EU affiliated insurers. Our sample consists of three types of EU affiliated insurers: (1) U.S. insurers affiliated to a EU-based insurance group, which comply with both RBC and Solvency II (*EU Affiliate_EU Parent*); (2) U.S. insurers with affiliates operating in the EU, which comply with RBC and whose affiliates comply with Solvency II (*EU Affiliate_U.S. Parent*); (3) U.S. insurers affiliated to an insurance group based in a third market, which comply with RBC and the solvency regulaiton in their group country (*EU Affiliate_Third Mkt Parent*). In our main results, we did not differentiate the three types of EU affiliated insurers, however, we would expect firms with an EU parent would have been more affected by the Solvency II reform than the other two types of EU affiliated insurers because of the group solvency rules in Solvency II. The results in Table A7 show that the coefficient of *EU Affiliate_U.S. Parent*× *Post* and *EU Affiliate_Third Mkt Parent*× *Post* in Columns (1)-(2) are negative, suggesting that EU affiliated insurers with a EU parent further improve their overall financial strength after the Solvency II reform, compared with the other two types of EU affiliated insurers. This observation is consistent with Solvency II's group supervision rules as we discussed in Section 2, where Solvency II is tougher for EU-based financial/insurance groups than for non-EU-based affiliates.

7 Conclusion

In this paper, we show that EU affiliated insurers operating in the U.S. insurance market appear to improve their financial strength measured by A.M. Best ratings relative to U.S. domestic insurers after the Solvency II reform. We support the regulatory transmission hypothesis in that EU affiliated insurers individually capitalized in the U.S. and legally separated from their home market parents/affiliates are also positively affected by Solvency II and therefore reduce their asset and underwriting risk-takings. The regulatory transmission effects exist because the group supervision of Solvency II encourages more prudent business practice and applies to the whole insurance/financial group including subsidiaries beyond the EU border. We do not find evidence that EU affiliated insurers increase capital holdings or increase reinsurance cession to unaffiliated insurers. Rather, we find that EU affiliated insurers cede more insurance business to their shadow reinsurers in third countries compared to U.S. domestic insurers after the Solvency II reform. Consistent with the literature on shadow insurance, we show that the major insurance rating agency does not adequately capture the potential risk of shadow insurance use by the U.S. P/C insurers. Taking shadow insurance use into account, the seemingly improved financial strength of EU affiliated insurers disappears and shadow insurance use is associated with a heightened overall insolvency risk of EU affiliated insurers compared to U.S. domestic insurers after the Solvency II reform. We support the behind-the-scenes arbitrage hypothesis in that insurers circumvent the stringent regulation using shadow insurance. Our study provides the first piece of evidence that the regulatory transmission effect is offset by the regulatory arbitrage effect. Our contribution also lies with the identification of shadow insurance use in the non-life insurance industry.

Our findings highlight the limitation of group supervision in reducing regulatory arbitrage and in disciplining the risk-taking of foreign subsidiaries given the existence of shadow insurance and shadow reinsurers. Regulators are advised to take into account both the appearing transmission effects and the behind-the-scenes arbitrage effects when designing a regulatory reform. The U.S. and EU regulators should reevaluate and update RBC and Solvency II to impose some capital requirements or quanlitative requirement also on shadow insurance. To provide more insightful policy implications, it may also be useful to compare the financial performance and operational efficiency of EU affiliated insurers relative to U.S. domestic insurers in light of the Solvency II reform.

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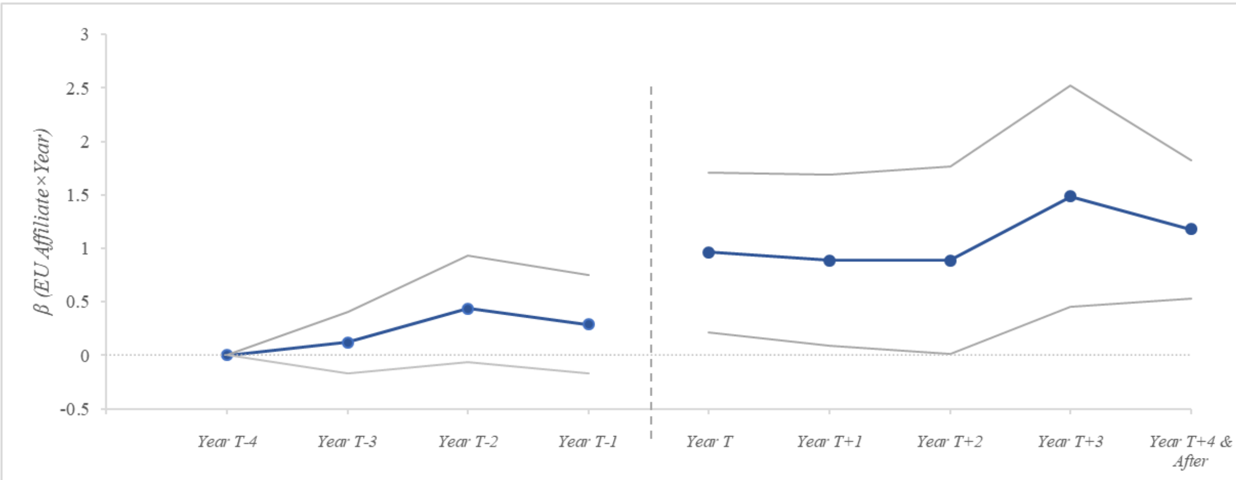
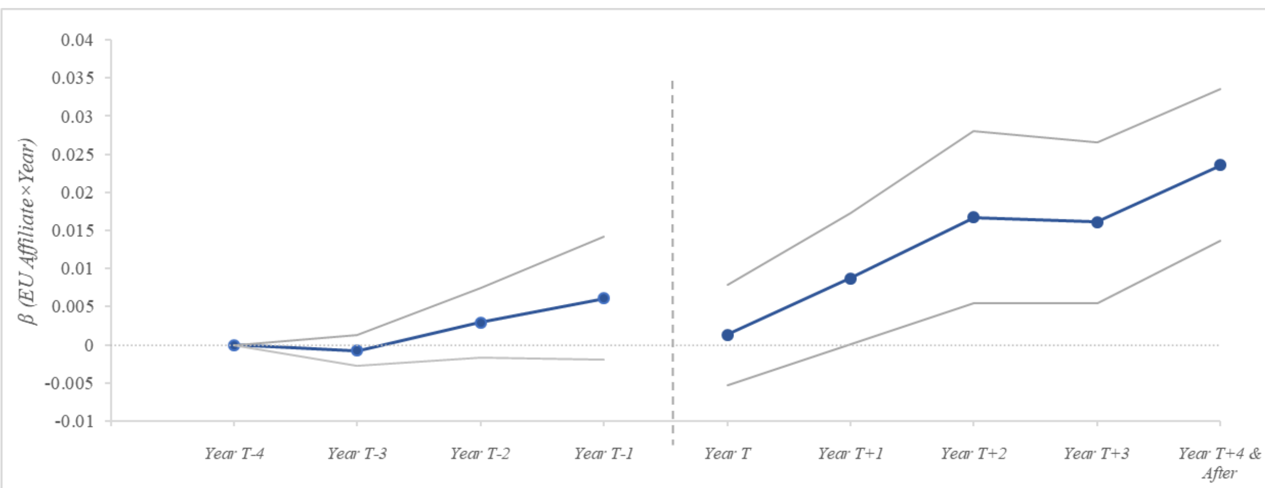
Figures

Figure 1: Parallel Trend for ***H1***



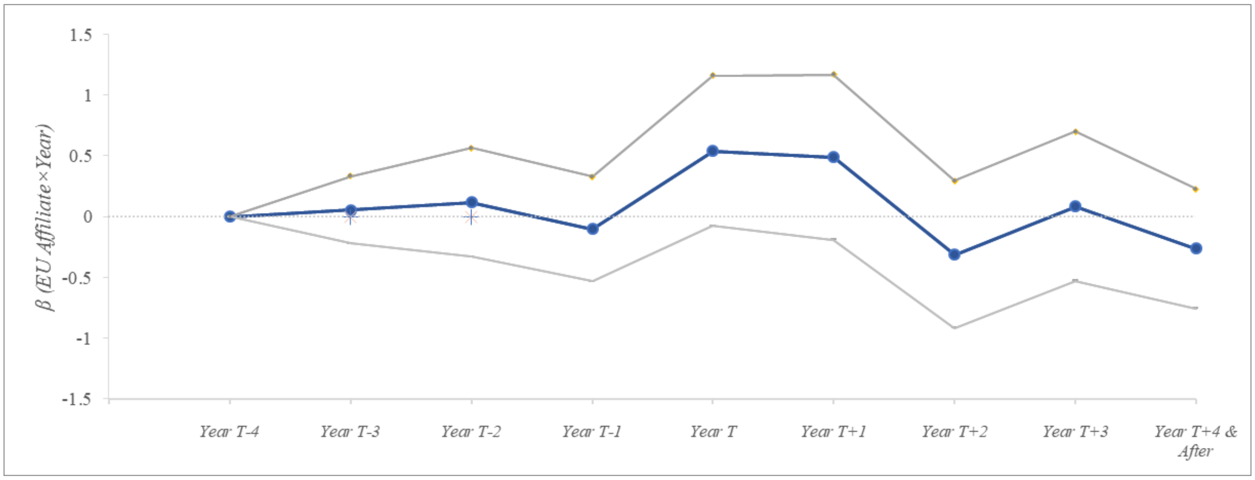
Notes: This figure presents the coefficients and the associated 90 percent confidence intervals in Column (3) of Table 3 estimated from the Equation (14).

Figure 2: Parallel Trend for ***H3***



Notes: This figure presents the coefficients and the associated 90 percent confidence intervals in Column (3) of Table 5 estimated from the Equation (17). The difference in shadow insurance use between EU affiliated and U.S. domestic insurers appears one year after the Solvency II event year. Considerging Solvency II event year T is defined as 2010 since the Solvency II Directive and its official quantitative capital impact analyses (QIS5) were released at the end of 2009 and in the middle of 2010, respectively. And because reinsurance renewals periods at typically at the first half of the year, it takes another year for EU affiliated insurers to effectively adjust their reinsurance arrangement.

Figure 3: Parallel Trend for *H5*



Notes: This figure presents the coefficients and the associated 90 percent confidence intervals in Column (3) of Table 7 estimated from the Equation (15) with *Adj AMB rating* as the dependent variable.

Tables

Table 1: Variable Definitions

Variables	Definitions
Key Variables	
AMB Rating	3 if AMB rating is A-, A, A+, or A++, 2 if AMB rating is B-, B, B+, or B++, 1 if AMB rating is C++ or below
EU Affiliate	Dummy variable equals 1 if an EU affiliated insurer and 0 if a U.S. domestic insurer
Asset Risk	An insurer's asset portfolio risk defined by Formula (1)
Underwriting Risk	Standard deviation of an insurers' loss ratio over the past four years
Capital Holding	Capital divided by total liabilities
Unaffiliated Reinsurance	Net reinsurance ceded to unaffiliated reinsurers divided by total premiums earned
Shadow Insurance	The premium ceded to shadow reinsurers divided by total premiums ceded, where the shadow reinsurers are affiliated, unauthorized, and AMB unrated reinsurers following Koijen and Yogo (2016)
Shadow Insurance Use	Dummy variable equals 1 if the premium ceded to shadow reinsurers is positive and 0 otherwise
Adj AMB Rating	AMB rating adjusted for shadow insurance use following Koijen and Yogo (2016)
Control Variables	
Size	Log of average total assets at the beginning and the end of a year
Geographic HHI	Herfindhal index based on direct premium written by state for each insurer
Business HHI	Herfindhal index based on direct premium written by lines of business for each insurer
Loss Ratio	Incurred losses and loss adjusted expenses divided by net premiums earned
Mutual	Dummy variable equals 1 if a mutual insurer and 0 otherwise
Growth	One-year growth rate in total assets
ROE	Net income divided by total equit

Table 2: Summary Statistics

Variables	Mean	St.Dev.	Min	P10	P50	P90	Max	N
Key Variables								
AMB Rating	2.8247	0.4022	1	2	3	3	3	17,340
EU Affiliate	0.2534	0.435	0	0	0	1	1	17,290
Asset Risk	0.6023	0.3377	0.0006	0.0961	0.6233	1.046	1.2463	17,340
Underwriting Risk	0.0865	0.0857	0.0072	0.0191	0.06	0.1804	0.4883	17,167
Capital Holding	1.3574	2.1097	0.2245	0.387	0.7788	2.395	16.5255	17,336
Unaffiliated Reinsurance	0.1185	0.3054	-1.6098[a]	-0.0004[a]	0.0603	0.4266	1.1933	16,773
Shadow Insurance	0.0093	0.0746	0	0	0	0	1	16,880
Shadow Insurance Use	0.0469	0.2113	0	0	0	0	1	16,880
Adj AMB rating	2.8129	0.4162	1	2	3	3	3	15,925
Control Variables								
Size	12.7261	1.7488	9.0793	10.5476	12.6535	15.0747	17.6752	17,340
Geographic HHI	0.4979	0.3797	0.0413	0.0634	0.3953	1	1	17,340
Business HHI	0.4936	0.2792	0.1213	0.1886	0.4149	1	1	17,340
Loss Ratio	0.6515	0.2167	0.0076	0.4069	0.6661	0.8399	1.6397	17,340
Mutual	0.1966	0.3974	0	0	0	1	1	17,340
Asset Growth	0.0656	0.1737	-0.3225	-0.0661	0.0433	0.1929	1.0924	17,340
ROE	0.0548	0.092	-0.302	-0.0392	0.0558	0.1531	0.3325	17,336

[a] The negative values indicate that the premiums assumed from unaffiliated insurers are more than premiums ceded to unaffiliated reinsurers.

Table 3: Results for Financial Strength (H1)

VARIABLES	(1) *AMB Rating*	(2) *AMB Rating*	(3) *AMB Rating*
EU Affiliate	1.9545***	1.4717***	1.2891***
	(0.2291)	(0.2606)	(0.2646)
$EU\ Affiliate \times Post$		0.9264***	
		(0.3164)	
$EU\ Affiliate \times Year_{T-3}$			0.1211
			(0.1732)
$EU\ Affiliate \times Year_{T-2}$			0.4359
			(0.3007)
$EU\ Affiliate \times Year_{T-1}$			0.2907
			(0.2813)
$EU\ Affiliate \times Year_{T}$			0.9632**
			(0.4556)
$EU\ Affiliate \times Year_{T+1}$			0.8903*
			(0.4876)
$EU\ Affiliate \times Year_{T+2}$			0.8876*
			(0.5313)
$EU\ Affiliate \times Year_{T+3}$			1.4870**
			(0.6295)
$EU\ Affiliate \times Year_{T+4 \text{ and after}}$			1.1815***
			(0.3923)
Size	0.5796***	0.5815***	0.5816***
	(0.0545)	(0.0546)	(0.0547)
Geographic HHI	-0.7308***	-0.7298***	-0.7296***
	(0.2000)	(0.1995)	(0.1995)
Business HHI	-0.3564	-0.3512	-0.3503
	(0.2251)	(0.2252)	(0.2252)
Loss Ratio	-0.7481***	-0.7491***	-0.7497***
	(0.2444)	(0.2437)	(0.2438)
Mutual	0.1484	0.1465	0.1462
	(0.1630)	(0.1631)	(0.1631)
Asset Growth	1.1125***	1.1149***	1.1145***
	(0.2058)	(0.2050)	(0.2052)
ROE	2.6235***	2.6253***	2.6198***
	(0.5627)	(0.5605)	(0.5617)
Year fixed effects	Yes	Yes	Yes
State fixed effects	Yes	Yes	Yes
Observations	17,286	17,286	17,286
Pseudo R-sq.	0.2357	0.2367	0.2369

Notes: This table reports the coefficients from ordered logit regressions of Equations (13) and (14). A.M. Best financial strength rating is used as the dependent variable to measure firms' overall insolvency risk. The standard errors in parentheses are heteroskedasticity-consistent and allow for clustering at the firm level. *, **, *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. Constants are included but not reported.

Table 4: Conventional Channel Tests: Asset Risk and Underwriting Risk (H2)

VARIABLES	(1) *Asset Risk*	(2) *Asset Risk*	(3) *Asset Risk*	(4) *Underwriting Risk*	(5) *Underwriting Risk*	(6) *Underwriting Risk*
EU Affiliate	-0.0695***	-0.0206	-0.0205	0.0250***	0.0337***	0.0325***
	(0.0169)	(0.0202)	(0.0224)	(0.0037)	(0.0053)	(0.0065)
EU Affiliate×*Post*		-0.0758***			-0.0161***	
		(0.0178)			(0.0054)	
EU Affiliate×$Year_{T-3}$			0.0155			0.0021
			(0.0121)			(0.0044)
EU Affiliate×$Year_{T-2}$			-0.0084			0.0043
			(0.0157)			(0.0056)
EU Affiliate×$Year_{T-1}$			-0.0066			-0.0015
			(0.0192)			(0.0074)
EU Affiliate×$Year_{T}$			-0.0337*			
			(0.0204)			
EU Affiliate×$Year_{T+1}$			-0.0401*			
			(0.0239)			
EU Affiliate×$Year_{T+2}$			-0.0509**			
			(0.0237)			
EU Affiliate×$Year_{T+3}$			-0.0894***			-0.0158**
			(0.0248)			(0.0078)
EU Affiliate×$Year_{T+4 \text{ and after}}$			-0.0947***			-0.0147**
			(0.0249)			(0.0068)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
State fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	17,286	17,286	17,286	13,183	13,183	13,183
Pseudo R-sq.	0.1389	0.1409	0.1417	0.1363	0.1379	0.1379

Notes: The table presents the estimated coefficients of OLS regressions of Equation (15). The standard errors in parentheses are heteroskedasticity-consistent and allow for clustering at the firm level. *, **, *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. Constants are included but not reported.

Table 5: Unconventional Channel Tests: Shadow Reinsurance Use (H3)

VARIABLES	(1)	(2) Panel A *Shadow Insurance*	(3)
EU Affiliate	0.0106**	0.0005	-0.0016
	(0.0042)	(0.0034)	(0.0027)
EU Affiliate$\times$*Post*		0.0155***	
		(0.0046)	
EU Affiliate$\times Year_{T-3}$			-0.0008
			(0.0012)
EU Affiliate$\times Year_{T-2}$			0.0029
			(0.0028)
EU Affiliate$\times Year_{T-1}$			0.0061
			(0.0049)
EU Affiliate$\times Year_{T}$			0.0013
			(0.0040)
EU Affiliate$\times Year_{T+1}$			0.0087*
			(0.0052)
EU Affiliate$\times Year_{T+2}$			0.0167**
			(0.0069)
EU Affiliate$\times Year_{T+3}$			0.0161**
			(0.0064)
EU Affiliate$\times Year_{T+4\text{ and after}}$			0.0236***
			(0.0060)
Controls	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
State fixed effects	Yes	Yes	Yes
Observations	16,826	16,826	16,826
Pseudo R-sq.	0.0435	0.0452	0.0467
		Panel B	
	Shadow Insurance to EU	*Shadow Insurance to U.S.*	*Shadow Insurance* to *Third Markets*
EU Affiliate	0.0014	-0.0015	0.0018
	(0.0010)	(0.0011)	(0.0035)
EU Affiliate$\times$*Post*	0.0016	0.0020	0.0108***
	(0.0019)	(0.0017)	(0.0033)
Controls	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
State fixed effects	Yes	Yes	Yes
Observations	16,591	16,829	16,826
Pseudo R-sq.	0.0093	0.0078	0.0457

Notes: The table presents the estimated coefficients of OLS regressions of Equations (16) and (17). *Shadow Insurance* is the percentage of insurance premium ceded to all shadow reinsurers over total premium ceded. *Shadow Insurance to EU* is the percentage of insurance premium ceded to shadow reinsurers in EU markets over total premium ceded. *Shadow Insurance to U.S.* is defined as the percentage of insurance premium ceded to shadow reinsurers in U.S. markets over total premium ceded. *Shadow Insurance to Third Markets* is the percentage of insurance premium ceded to shadow reinsurers in the third markets other than EU or U.S. markets over total premium ceded. The standard errors in parentheses are heteroskedasticity-consistent and allow for clustering at the firm level. *, **, *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. Constants are included but not reported.

Table 6: Financial Strength Rating and Shadow Reinsurance (H4)

	(1)	(2)	(3)	(4)
	Panel A		Panel B	
VARIABLES	*AMB Rating*		*Adj AMB Rating*	
Shadow Insurance	0.0538	0.6556	-7.0661***	-7.4120***
	(0.7308)	(0.8742)	(0.5739)	(0.5431)
Size	0.6214***	2.1921***	0.6112***	2.1265***
	(0.0559)	(0.3081)	(0.0539)	(0.3036)
Geographic HHI	-0.8400***		-0.8075***	
	(0.1981)		(0.1945)	
Business HHI	-0.3113		-0.2385	
	(0.2273)		(0.2246)	
Loss Ratio	-0.7645***		-0.7245***	
	(0.2158)		(0.2125)	
Mutual	-0.1030		-0.0712	
	(0.1677)		(0.1669)	
Asset Growth	0.9732***		0.9632***	
	(0.1916)		(0.1889)	
ROE	2.9259***	2.2724***	2.9636***	2.2786***
	(0.5359)	(0.4666)	(0.5265)	(0.4644)
Log Liabilities		-0.1464**		-0.1493**
		(0.0663)		(0.0667)
Capital Holding		-1.2809***		-1.2299***
		(0.2926)		(0.2908)
RBC ratio		0.0449***		0.0467***
		(0.0161)		(0.0163)
Stock Company		0.2955*		0.2621*
		(0.1541)		(0.1520)
Year fixed effects	Yes	Yes	Yes	Yes
State fixed effects	Yes	Yes	Yes	Yes
Observations	16,876	16,759	16,876	16,759
Adj R-sq.	0.2096	0.2505	0.2289	0.2704

Notes: The table presents the estimated coefficients of ordered logit regressions of Equation (18). The standard errors in parentheses are heteroskedasticity-consistent and allow for clustering at the firm level. *, **, *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. Constants are included but not reported.In these tests, we use two alternative sets of control variables. The first set in Columns (1) and (3) is as defined in Equation (13). To comply with Koijen and Yogo (2016), we also additionally use *ROE*, *Size*, *Log Liabilities*, *Capital Holding*, *RBC Ratio*, and *Stock Company* as the second set of control variables in Columns (2) and (4).

Table 7: Adjusted AMB Rating and Shadow Reinsurance (H5)

	(1)	(2)	(3)	(4)
		Panel A		Panel B
VARIABLES		*Adj AMB Rating*		*Adj AMB Rating*
EU Affiliate	1.2332***	1.2931***	1.2793***	1.5400***
	(0.1847)	(0.2346)	(0.2550)	(0.1616)
EU Affiliate$\times$*Post*		-0.0957		0.9017***
		(0.2420)		(0.2484)
EU Affiliate$\times Year_{T-3}$			0.0551	
			(0.1677)	
EU Affiliate$\times Year_{T-2}$			0.1192	
			(0.2725)	
EU Affiliate$\times Year_{T-1}$			-0.1015	
			(0.2611)	
EU Affiliate$\times Year_{T}$			0.5416	
			(0.3768)	
EU Affiliate$\times Year_{T+1}$			0.4909	
			(0.4133)	
EU Affiliate$\times Year_{T+2}$			-0.3112	
			(0.3680)	
EU Affiliate$\times Year_{T+3}$			0.0853	
			(0.3729)	
EU Affiliate$\times Year_{T+4 \text{ and after}}$			-0.2644	
			(0.2997)	
EU Affiliate$\times$*Post*$\times$*Shadow Insurance Use*				-0.9909*
				(0.5933)
EU Affiliate$\times$*Shadow Insurance Use*				-1.3314***
				(0.5100)
Shadow Insurance Use				-1.4715***
				(0.3027)
Shadow Insurance Use$\times$*Post*				-0.1036
				(0.3514)
Controls	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
State fixed effects	Yes	Yes	Yes	Yes
Observations	17,282	17,282	16,826	16,826
Adj R-sq.	0.1978	0.1979	0.1984	0.2250

Notes: The table presents the estimated coefficients of ordered logit regressions of Equations (13), (14) and (20). The standard errors in parentheses are heteroskedasticity-consistent and allow for clustering at the firm level. *, **, *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. Constants are included but not reported.

Appendix A Proofs

Proof of Proposition 1

Proof. 1. By Lemma 1 and 2, the difference in the insurer's optimal investment in the risky asset is $X_r^{**} - X_r^{*} = \frac{\theta(L^* - L^{**}) - \Delta}{\delta}$. As we show in Part 2 of the proof, $L^* - L^{**} > 0$. Suppose the regulation difference Δ is higher than a threshold $\widetilde{\Delta}$, where $\widetilde{\Delta} = \theta(L^* - L^{**})$, We have $X_r^{**} < X_r^{*}$. In contrast, if regulation difference Δ is less than a threshold $\widetilde{\Delta}$, we have $X_r^{**} > X_r^{*}$.

2. We plug Equation (6) into Equation (5), the optimal insurance price is determined by the following implicit function.

$$\gamma^H + (R^H - 1)\frac{\theta}{\delta} - \frac{P^*(1-p)(1-q)(R^H-1)^2}{bL'(P^*)} - \frac{L(P^*)}{L'(P^*)} - P^* = 0$$

We define

$$\Phi(P^*) = \frac{\gamma^H + (R^H - 1)\frac{\theta}{\delta}}{P^*} - \frac{(1-p)(1-q)(R^H-1)^2}{bL'(P^*)} + \frac{1}{\epsilon(P^*)} - 1 \tag{A21}$$

where $\epsilon(P^*) = -\frac{L(P^*)}{L'(P^*)P^*}$ is the price elasticity function for insurance demand.

We assume (i) the insurance price elasticity function for insurance demand weakly increases with insurance price P,that is $\frac{\partial \epsilon(P)}{\partial P} \geq 0$; (ii) $L''(P) \geq 0$. Thus $\frac{\partial \Phi(P)}{\partial P} < 0$. There exists a unique solution to Equation (A21) such that $\Phi(P^*) = 0$.

We then plug Equation (6) into Equation (5), the optimal insurance price is determined by

$$\gamma^H + \frac{\omega\theta}{(1-p)(1-q)} + (R^H - 1)\frac{\theta}{\delta} - \frac{P^{**}(1-p)(1-q)(R^H-1)^2}{bL'(P^{**})} - \frac{L(P^{**})}{L'(P^{**})} - P^{**} = 0$$

We define

$$\Psi(P^{**}) = \frac{\gamma^H + \frac{\omega\theta}{(1-p)(1-q)} + (R^H - 1)\frac{\theta}{\delta}}{P^{**}} - \frac{(1-p)(1-q)(R^H-1)^2}{bL'(P^{**})} - \frac{1}{\epsilon(p^{**})} - 1. \tag{A22}$$

Because $\Psi(P^*) - \Phi(P^*) = \frac{\omega\theta}{P^*} > 0$,we have $\Psi(P^*) > \Phi(P^*) = 0$. Further, because $\frac{\partial \Psi(P)}{\partial P} < 0$, there exists a unique solution to Equation A22 such that $\Psi(P^{**}) = 0$. It follows that $\Psi(P^*) > 0 = \Psi(P^{**})$. Therefore, $P^* < P^{**}$.

3. The optimal amount of shadow insurance use is determined by $C'(S) = Pq(R^H - 1)$. By the proof of Part 2, we have

$$C'(S^{**}) = P^{**}(1-p)(1-q)(R^H - 1) > P^*(1-p)(1-q)(R^H - 1) = C'(S^*).$$

Because $C''(\cdot) > 0$, we can show that $S^{**} > S^*$.

4. Further, let U denote the underwriting risk measured by the underwriting liabilities on insurer's balance sheet, that is $U = L - S$. Thus, the difference of underwrting risk of

insurers with and without group regulation is

$$U^{**} - U^{*} = (L^{**} - S^{**}) - (L^{*} - S^{*}) = \overbrace{(L^{**} - L^{*})}^{<0} - \overbrace{(S^{**} - S^{*})}^{>0} < 0$$

. Therefore $U^{**} < U^{*}$.

□

Appendix B Alternative Explanations and Additional Results

Table A1: Conventional Channel Tests: Capital and Reinsurance

VARIABLES	(1) *Capital Holding*	(2) *Capital Holding*	(3) *Capital Holding*	(4) *Unaffiliated Reinsurance*	(5) *Unaffiliated Reinsurance*	(6) *Unaffiliated Reinsurance*
EU Affiliate	0.2260**	0.2702**	0.2031*	-0.0446***	-0.0346*	-0.0411*
	(0.0966)	(0.1146)	(0.1195)	(0.0163)	(0.0189)	(0.0229)
EU Affiliate×*Post*		-0.0685			-0.0154	
		(0.0907)			(0.0174)	
EU Affiliate×$Year_{T-3}$			0.0138			0.0049
			(0.1031)			(0.0154)
EU Affiliate×$Year_{T-2}$			0.0902			0.0161
			(0.1284)			(0.0183)
EU Affiliate×$Year_{T-1}$			0.1634			0.0046
			(0.1352)			(0.0202)
EU Affiliate×$Year_{T}$			0.0803			-0.0083
			(0.1355)			(0.0223)
EU Affiliate×$Year_{T+1}$			0.0872			-0.0307
			(0.1434)			(0.0255)
EU Affiliate×$Year_{T+2}$			-0.0595			-0.0187
			(0.1377)			(0.0254)
EU Affiliate×$Year_{T+3}$			-0.0323			-0.0280
			(0.1438)			(0.0274)
EU Affiliate×$Year_{T+4 \text{ and after}}$			-0.0220			0.0001
			(0.1294)			(0.0249)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
State fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	17,286	17,286	17,286	16,721	16,721	16,721
Pseudo R-sq.	0.1137	0.1137	0.1138	0.0461	0.0462	0.0465

Notes: The table presents the estimated coefficients of OLS regressions of Equation (15). The standard errors in parentheses are heteroskedasticity-consistent and allow for clustering at the firm level. *, **, *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. Constants are included but not reported.

Table A2: Cumulative Abnormal Returns (CARs) for EU Insurance Companies under Solvency II around Event Dates

Event Dates	(1) November 25th, 2009	(2) January 1st, 2016
CAR(-1,1)	-1.1680%**	-0.0185%
	(0.0160)	(0.8651)
CAR(-2,2)	-1.1098%**	0.0170%
	(0.0473)	(0.9287)
CAR(-5,5)	-2.1122%**	-0.2316%
	(0.0131)	(0.3975)
Number of insurers	112	133

Notes: This table presents the results for event study. Columns (1)-(2) show the cumulative abnormal returns (CARs) using the day when official Solvency II Directive (2009/28/CE) was published (i.e. November 25th , 2009) and when Solvency II reform was officially implemented (i.e. January 1st, 2016) as the event date, respectively. CAR(-t_1, t_2) denotes the CAR from day t_1 before the event date to day t_2 after the event date. The standard errors in parentheses are heteroskedasticity-consistent and allow for clustering at the firm level. *, **, *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively.

Table A3: Robustness Tests Using A.M. Best Rating Change

	(1)	(2)	(3)	(4)
	Panel A		Panel B	
VARIABLES	*AMB Rating Change*		*Adj AMB Rating Change*	
EU Affiliate	0.0969	-0.3185	0.0084	-0.0980
	(0.1111)	(0.2137)	(0.1063)	(0.1809)
EU Affiliate×Post		0.6608***		0.1646
		(0.2533)		(0.2220)
Size	-0.0566*	-0.0555*	-0.0564**	-0.0561**
	(0.0326)	(0.0325)	(0.0274)	(0.0274)
Geographic HHI	0.3577**	0.3536**	0.4130***	0.4120***
	(0.1482)	(0.1479)	(0.1238)	(0.1238)
Business HHI	-0.0841	-0.0751	-0.2424	-0.2405
	(0.1718)	(0.1718)	(0.1502)	(0.1504)
Loss Ratio	0.0910	0.0934	-0.0459	-0.0458
	(0.2789)	(0.2781)	(0.2648)	(0.2647)
Mutual	-0.1226	-0.1226	0.0379	0.0373
	(0.1307)	(0.1295)	(0.0969)	(0.0967)
Asset Growth	1.5338***	1.5420***	0.6716*	0.6732*
	(0.3428)	(0.3414)	(0.3884)	(0.3881)
ROE	6.2970***	6.2908***	5.0195***	5.0191***
	(0.7834)	(0.7744)	(0.6663)	(0.6643)
Year fixed effects	Yes	Yes	Yes	Yes
State fixed effects	Yes	Yes	Yes	Yes
Observations	16,876	16,759	16,876	16,759
Adj R-sq.	0.2096	0.2505	0.2289	0.2704

Notes: The standard errors in parentheses are heteroskedasticity-consistent and allow for clustering at the firm level. *, **, *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. Constants are included but not reported.

Table A4: Palcebo Test Using 2008 as Event Year

VARIABLES	(1) *AMB Rating*	(2) *Adj AMB Rating*	(3) *Shadow Insurance*
EU Affiliate	1.4129***	1.3489***	-0.0004
	(0.2587)	(0.2494)	(0.0028)
EU Affiliate×Placebo Post	0.3048	-0.0232	0.0047
	(0.2210)	(0.2059)	(0.0032)
Size	0.4904***	0.4811***	0.0004
	(0.0560)	(0.0545)	(0.0011)
Geographic HHI	-0.8958***	-0.7803***	-0.0069
	(0.2112)	(0.2070)	(0.0047)
Business HHI	-0.2589	-0.2940	0.0114
	(0.2452)	(0.2414)	(0.0071)
Loss Ratio	-0.4922*	-0.5121*	0.0084
	(0.2667)	(0.2653)	(0.0064)
Mutual	0.3007*	0.2959*	-0.0027
	(0.1789)	(0.1760)	(0.0018)
Asset Growth	0.9200***	0.9069***	-0.0018
	(0.2606)	(0.2533)	(0.0033)
ROE	2.5985***	2.4688***	0.0123
	(0.7297)	(0.7144)	(0.0148)
Year fixed effects	Yes	Yes	Yes
State fixed effects	Yes	Yes	Yes
Observations	5,458	5,455	5,277
Pseudo R-sq.	0.1878	0.1729	0.0076

Notes: The standard errors in parentheses are heteroskedasticity-consistent and allow for clustering at the firm level. *, **, *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. Constants are included but not reported.

Table A5: Palcebo Test Using Randomly Assigned Treatment Group

VARIABLES	(1) *AMB Rating*	(2) *Shadow Insurance*
EU Affiliate×Post	-0.0225	-0.0168
	(<0.01)	(<0.01)

Notes: This table reports the robustness placebo test. In these tests, we randomly assign companies as EU affiliate insurers based on the distribution of EU affiliate in our sample with replacement. In other words, the proportion of EU affiliate insurers in the placebo test sample are restricted as the same as that in our original sample. We replicate our main regression with significant coefficients for the variable of interest, i.e., Eq(13) and (16), and record the t-value of coefficient of *EU Affiliate × Post*. We repeat the procedure 500 times. This table reports the average t-value over the 500 regressions. The numbers in parentheses show the percentile of this sampling distribution below which the actual t-value in our main regression lies.

Table A6: Results Excluding Companies with Third Market Affiliates

VARIABLES	(1) AMB Rating	(2) Adj AMB Rating	(3) Shadow Insurance
EU Affiliate	1.4761***	1.2951***	0.0025
	(0.2661)	(0.2396)	(0.0032)
EU Affiliate×Post	0.8673***	-0.1956	0.0180***
	(0.3212)	(0.2458)	(0.0047)
Size	0.6286***	0.5879***	-0.0000
	(0.0565)	(0.0527)	(0.0010)
Geographic HHI	-0.6274***	-0.4548**	-0.0102***
	(0.2095)	(0.1957)	(0.0037)
Business HHI	-0.2344	-0.2179	0.0084
	(0.2397)	(0.2277)	(0.0053)
Loss Ratio	-0.9849***	-0.7986***	-0.0079
	(0.2619)	(0.2498)	(0.0089)
Mutual	0.1178	0.1456	-0.0035**
	(0.1690)	(0.1625)	(0.0016)
Asset Growth	1.0799***	1.0245***	-0.0033
	(0.2301)	(0.2150)	(0.0033)
ROE	2.0336***	1.9887***	-0.0055
	(0.6164)	(0.5742)	(0.0123)
Year fixed effects	Yes	Yes	Yes
State fixed effects	Yes	Yes	Yes
Observations	15,482	15,479	15,078
Pseudo R-sq.	0.2507	0.2098	0.0467

Notes: This table reports the results using the sample excluding observations for insurers with ultimate parents or affiliated insurers in a third country other than EU and the U.S.. The standard errors in parentheses are heteroskedasticity-consistent and allow for clustering at the firm level. *, **, *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. Constants are included but not reported.

Table A7: Difference among Different Types of EU Affiliated Insurers

	(1) AMB Rating	(2) Adj AMB Rating
EU Affiliate	0.6144*	0.2559
	(0.3733)	(0.3196)
EU Affiliate×Post	3.2346***	0.8779*
	(0.7662)	(0.4915)
EU Affiliate_U.S. Parent	0.8029	1.0508**
	(0.5820)	(0.5215)
EU Affiliate_U.S. Parent×Post	-3.1181***	-1.2426**
	(0.8747)	(0.5898)
EU Affiliate_Third Mkt Parent	1.4308**	1.7638***
	(0.5568)	(0.4795)
EU Affiliate_Third Mkt Parent×Post	-1.7374*	-1.5238**
	(0.8999)	(0.6144)
Controls	Yes	Yes
Year fixed effects	Yes	Yes
State fixed effects	Yes	Yes
Observations	17,286	17,283
Adj (or Pseudo) R-sq.	0.2398	0.1999

Notes: The standard errors in parentheses are heteroskedasticity-consistent and allow for clustering at the firm level. *, **, *** indicate that the coefficients significantly differ from 0 at the 10%, 5%, and 1% levels, respectively. Constants are included but not reported.