Hedge the Hedgers: Usage of Reinsurance and Derivatives by PC Insurance Companies

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Abstract

This paper studies the usage of two common hedging tools, reinsurance and derivatives, by property and casualty insurance companies. In a simple mean-variance efficient optimization model, the two hedging tools display substitutive effect when asset and liability do not display strong natural hedging. We verify this relationship using a six-year insurance company firm-level data on reinsurance usage and off-balance sheet derivative trading recorded between 2000 and 2005. Controlling for firm specific variables, such as asset-liability composition, loss development and credit rating, such substitution effect indeed exists in the insurance companies' hedging decisions under a two-stage simultaneous equation framework.

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1 Introduction

As financial intermediaries, the insurance companies are exposed under various sources of risk, including interest rate, exchange rate, credit and underwriting risk (Cummins, Phillips and Smith (1997) (2001), Colquitt and Hoyt (1997)). More importantly, due to the sensitivity towards changes in capital level as a financial risk shelter from adverse development, the negative impact from these external risk factors can immediately affect the operation of insurance companies, much more direct than what is observed in the non-financial industries.

There are two major sources for capital shocks, the fluctuation in asset value due to investment in risky asset and volatility in loss claims. It is not difficult to understand the fluctuation in asset value invested in the form of stocks. Although one may argue that insurance companies should be largely immune from investment volatility, as majority of their assets are invested in the form of bonds, yet adverse development in the interest rate can still hurt bond values, and expose insurance companies under financial distress. On the other arm of operation, sudden surge in the loss claim frequency or severity can seriously hurt the capital base of the underwriting company. In particular, as the risk hedger for catastrophic loss events, the property and casualty (PC) insurance companies face potential devastating loss claims, which can cast doubt on the underwriting ability or even the solvency of the entire company. Moreover, when catastrophic events spike up the loss claims, the stock market tends to be distressed as a by-product, as is the case after September 11 and Hurricane Katrina. As a result, the PC companies are under double whammy towards adverse development in the capital market.

When the relative value of assets to loss liability shrinks due to changes in external risk factors, insurance companies need to find ways to restore capital to guarantee normal operation. One choice, external capital, can be raised through equity or bond offerings to restore asset-liability gap. Unfortunately, due the capital market imperfection caused by the asymmetric information between the investors and managers, external capitals tend to be fairly expensive. Lee et al. (1996) document the average cost of raising external capital by the U.S. corporations: seasoned equity offering (SEO) is found to be the most expensive, with direct expenses counts for over 7 percent of the total proceeds raised. Bond offerings, in comparison, are relatively cheaper, with direct cost ranging between 2 to 4 percent, depending on the form of debt issued. For PC insurance companies who try to raise capital through debt after major capital shock, bond holders are expected to demand a much higher risk premium than the average across industries. And the indirect cost of external financing, namely the increase in leverage ratio due to bond offerings and the long run underperformance due to equity offerings (Loughran and Ritter (1995) (2000), Spiess and Affleck-Graves (1995)), can potentially push the issuing companies into further financial distress.

Internal capital can be seen as an apparent inexpensive alternative to restore the capital. Nevertheless, the accumulation through retained earning is usually much slower compared to the external fund raising. The implied cost, however, is the forgone positive NPV projects due to capital constraints (Froot et al. (1993), Froot (2007)), and they can be as costly as the external funding raising expenses, if not more.

Hedging activities are crucial for the insurance companies against the exposure to the external risk factors, for alleviating the financial and economical stress due to imperfect capital market. The most commonly used ones are reinsurance and off-balance sheet derivative hedging. As a result of the maturity in the financial engineering techniques in the past decade, hedging external risks using derivatives has become more popular among the insurers and reinsurers. Conventional derivatives, such as options, forwards and futures for interest rate, exchange rate and credit risks are seen in insurance companies' annual report. In addition to the traditional vehicle of hedging underwriting risk, reinsurance, we have also seen the emergence of more innovative derivatives for extreme loss events, such as CAT bonds and sidecars as a by-product of recent years' major natural and man-made catastrophes (Cummins (2006), Guy Carpenter (2005) (2006)).

Inspired by the recent market development, we find it important to study the hedging behavior of PC insurance companies in a systematic way. We model the hedging decision of a utility-maximizing PC insurance company: the level of reinsurance usage and the derivative hedging, focusing on the optimal level of usage of both hedging tools as well as the interaction between these two. For companies with mean-variance efficient type of utility function, reinsurance and derivative hedging are found to be substitution of each other, when the asset and liability do not display high positive correlation. In other words, when the natural value hedge between asset and liability is not too strong, more usage of reinsurance can release the company's capital to tolerate more risk taking on the asset investment side. Similarly, stabler asset value due to more derivative hedging can reduce the capital constraint caused by investment volatility, and allow the insurer to retain more loss liability on its book.

Firm-level data of insurance companies between 2000 and 2005 are used to test the hypothesis. Firm-specific information, such as size, profitability, leverage and credit ratings are used as control variables. Accounting information on off-balance sheet derivative transaction is obtained from Schedule DB of PC insurers' annual report to National Association of Insurance Commissioners (NAIC). Both the decision to use derivatives for hedging as well as the degree of involvement are analyzed in this paper. In addition, the degree of involvement is measured using both notional amount and market value of the derivative positions taken by the insurance companies. While notional amount provides an intuitive impression of the volume engaged, the market value reflects the true economical value of these derivative positions. Therefore, inspection on both can provide us with a more complete picture of the derivative hedging behavior. Two stage simultaneous equations are used to estimate the interaction between reinsurance and hedging activities. And Probit and Cragg's (1971) Tobit methods are used to estimate the hedging decision and volume respectively.

The plan of the paper is as the follows. Section 2 discusses the motivation for risk hedging and common measures taken. Section 3 models the optimal hedging decision of a utility-maximizing insurance company. We describe the data used for this research in Section 4. Empirical tests are presented in Section 5. And Section 6 concludes.

2 Reasons for Hedging and How to Proceed

2.1 Why to Hedge?

2.1.1 General Firms

Theoretically, investment products are believed to be fairly priced. The cost paid to engage in a particular hedging transaction should be equal to the discounted present value of loss shielded. Therefore, in a frictionless world, participating in hedging transaction is not value-increasing for the underlying company. In addition, as shareholders are believed to be capable of perfectly diversifying the idiosyncratic risk of holding the company stock in a complete market setup, there is no need to diversify the idiosyncratic risk at firm level. One may conclude that hedging is merely an unnecessary irrational behavior by the firm managers.

However, researchers justify the rational of hedging activities in the general finance literature as a result of the following market inefficiencies: i) Tax consideration. For value maximizing firms, hedging positions can help smoothing firms' taxable income and hence reduce the expected tax payment and increase firm value (Smith and Stulz (1985), Nance et al. (1993) and Mian (1996)). ii) Agency costs. In the classical asymmetric information context, firms use hedging positions as signals of transparency towards outsiders. And the investors tend to reward publicly traded firms with reported hedging transactions (Nelson et al. (2005)). On top of this, managers may also have the incentive to use hedging tools so as to maximize their expected utility from compensation (Smith and Stulz (1985), Whidebee and Wohar (1999)). iii) Financial distress costs. Various costs associated with financial distress, such as bankruptcy cost, encourage firms' participation in hedging transactions as well. Similar to the tax reduction argument, hedging positions help to smooth volatility in firm value and lower the probability of going under. Since this implied distress cost is significantly amplified in the financial industry, we will discuss the third aspect in more detail in the following section regarding insurance companies' hedging motivation.

2.1.2 Insurance Industry

Capital constraint theory proposed by Gron (1994) and Winter (1994) has been widely used to explain the cycles in the PC insurance industry. Based on the assumptions of inter-dependence of loss events, sensitivity of asset value with respect to external risk factors and cost difference between internal and external capital, researchers predict that there exists a short term capital deficit faced by the entire PC lines of business, and hence leads to the surge in insurance price and shrinkage in quantity of coverage provided. Although it was originally proposed to explain the liability cycle during the mid 1980s caused by medical malpractice and changes in interest rate, the capital constraint theory continues to be a good theoretical explanation for the recent years insurance cycles caused by September 11th and hurricane season of 2005.

Holding sufficient amount of capital is one way to get around the constraint problem. The current regulation requires that insurers hold minimum amount of capital for the outstanding liability. In fact, many firms are actually holding multiples of this minimum amount. Zanjani (2002) demonstrates that the optimal capital holding by line of business is determined by the volatility of the underlying loss distribution. Hence, for property and casualty insurance companies who provide protection against catastrophes, such as earthquake line of business and hurricane-prone states, the capital requirement is usually extremely high. Nevertheless, since it is costly to hold capital due to taxation reasons, firms can not hold the otherwise optimal amount of capital as surplus. If a firm is unwilling to bear the cost of holding extra capital, it may find itself under the exposure of capital constraint when catastrophic events really hit the market. In that case, additional fund will need to be raised in order to overcome the financial distress.

Plenty of theoretical and empirical evidence of cost difference between internal and external capital raising are presented in the finance literature. One common explanation is the asymmetric information between the managers and the external investors. For publicly traded companies, seasoned equity offering (SEO) is one option of external capital raising. The traditional pecking order theory predicts that internal accumulation or debt offerings are preferred to the equity issuance, since SEO will dilute the ownership of the company, which is undesirable if the issuing firms are actually profitable. As a result, firms will only turn to SEO as a final resort when the internal revenue accumulation is slow, or debt offering is not an available alternative. Therefore, the decision of SEO will be received as a negative signal regarding the profitability of the issuing company, and lead to price discount upon announcement. Lee (1997) provides additional evidence that for firms whose top executives sell company stocks before SEO, their stocks tend to underperform the benchmark following secondary offerings. On top of all that, various fees associated with SEO, such as spreads charged by investment banks, registration fees, legal and auditing fees (Lee et al. (1996)), all make equity offerings even less desirable.

Most of the companies in the PC insurance industry, however, are privately held. And significant percentage of them are organized in the mutual form rather than stock companies. Therefore, SEO does not appear to be a feasible external fund raising option, and bond offering is the only external fund raising choice left. Although lower fees are associated with bond issuing compared with equity offering, the same logic of asymmetric information between managers and investors applies to the bond issuing case. As debt holders do not have access to the information available to company insiders, they require a higher risk premium to compensate for the uncertainty of defaulting. Moreover, if insurance companies decide to reach out to the debt market for capital restoring after loss shocks or investment downturns, they will be penalized even more, as increasing leverage ratio during financial distress can really ring the alarm about the solvency of the issuing company. In fact, Lee et al. (1997) also show that the cost of debt issuing is determined by the credit quality of the issuer. The lower the credit quality, the higher the risk premium charged. This is exactly what a lot of the insurance companies face post capital shocks. As a result, neither equity offering nor debt issuing turns out to be an ideal channel for PC insurers to raise additional capital.

What remains as an option is to restore capital through internal revenue accumulation. However, cheap as it is compared to external fund raising, it usually takes much longer to raise the same amount of capital than through the external fund raising. The implied cost of this time-inefficient funding option can be illustrated as the follows: given the surge in demand for insurance coverage post major shocks, the insurance companies do have the market power to charge a higher price for the same level of coverage offered pre shock, the phenomenon of which is commonly referred to as the *hard market*. However, limited by the existing capital level, these insurers are restrained in the number of new contracts they can underwrite, which prevents them from taking full advantage of the high price era. Applying the same logic from the underwriting operation to the investment side, if an insurance company suffers from high volatility in its asset value, it will have less stable capital level for the underwriting operation, and hence bear the cost of missing out attractive investment opportunities due to capital constraints.

The cost of giving up positive NPV project is thoroughly discussed in Froot et al. (1993). Recent support for the cost of financial distress is presented by Korteweg (2006), where he estimates the average cost of financial distress for firms across industries ranges between 0 to 11 percent of firm value. For insurance industry specific, once the capital level is below the industry threshold, such as twice the risk based capital level, regulators and credit rating agencies will exert influence on the underlying company, and various costs will arise due to interruption of normal business operation. One recent example is the impact of the sub prime crisis on the bond insurers's credit standing. Two major bond insurers were required by Fitch to raise $1 billion USD within month and half in order to maintain their current high credit rating (WSJ (2007)). Last but not least, as consumers of insurance products are believed to be sensitive towards the quality of services purchased (Zanjani (2002) and Froot (2007)), the already distressed insurers may find themselves under more stringent scrutiny from policyholders, and are demanded to improve financial standing and provide price discount, if not losing the contract completely.

To summarize, if an insurance company can successfully hedge its risk in the underwriting arm as well as the investment arm, it will suffer much less from the financial distress due to capital constraint and the direct and indirect cost associated with capital raising. Therefore, optimal risk hedging is crucial to PC insurance companies' profitability and sustainability.

2.2 How to Hedge?

Reinsurance is the traditional hedging tool, which plays an extremely important role in hedging against underwriting risk for the primary PC insurers. Globally, $146 billion USD premium was ceded to reinsurers in the PC line of business in 2003, which counts for over 13 percent of total direct premium written.[1] In the U.S. PC market, around 60 percent of loss claims of September 11th Attack and 40 percent of loss claims from hurricane season 2005 are actually paid out by the reinsurance companies.[2] Although innovative derivatives such as CAT Bonds and Sidecars are getting more active in the catastrophe loss market, reinsurance still remains the number one choice for layering off the underwriting risk for majority of the primary PC insurance companies. In their study on demand for reinsurance, Cole and McCullough (2006) reinforce factors such as profitability, business distribution, reinsurance quality and scale of economy affect primary insurance companies' demand of reinsurance. Garven and Grace (2007) show that level of asymmetric information between the primary insurers and reinsurers also determines the level of reinsurance involvement. We will control the impacts from the above factors when studying interaction between reinsurance and derivatives in this paper.

Derivative hedging is a relatively new phenomenon in the insurance industry. In the general market, however, it has been widely used to hedge firms' asset value from adverse impacts, such as interest rate risk, exchange rate risk and credit risk. Using a survey data in 1986, Nance et al. (1993) show that convex tax structure, growth opportunities and lack of hedging substitutes encourage firms to engage in derivative hedging. In a later study using more comprehensive data in 1992, Mian (1996) finds mixed support for the above statement, in the sense that economy of scale is the only determining factor in firms' derivative hedging decisions. Geczy et al. (1997) focus on the the currency derivatives hedging behavior of subset of Fortune 500 nonfinancial firms. Again, they claim that firms that are more vulnerable to capital constraint and exchange rate risk are more likely to use currency derivatives.

[1] Swiss Re (2004)

[2] Disaster Insurance Project (2006), Wharton Risk Center

While derivative hedging appears to be important for firms in general, it is a particularly crucial tool for risk management for firms in the financial industry, since the value of most of their assets, liabilities, services provided and revenue generated are subject to all the external risk factors mentioned above. Using a sample of U.S. large commercial banks, Choi and Elyasiani (1997) conclude that banks' exposure in interest rate and exchange rate derivatives affects the respective betas. In fact, the exposure in the derivative positions increases the banks' systematic risk, which is opposite to the initial motivation for participating in derivative hedging. Managerial incentives are believed to affect banks' derivative participation as well (Whidbee and Wohar (1999)).

Among the few papers that investigate insurance companies' usage of derivative hedging, the common factors, such as economy of scales, financial distress, managerial incentives are found to be influential. Unique to the insurance industry, asset-liability duration gap (Cummins et al. (2001), Colquitt and Hoyt (1997)) is also found to be important in the decision as well as volume of derivatives used. Although reinsurance is included in both studies as a control variable, its impact on derivative participation and volume is ambiguous. We think the following limitations may have blurred the relationship, if there is any: i) Due to data limitation, both studies include all derivative positions shown in the annual statement of insurance companies as hedging-driven. In fact, only half of these reported derivative transactions are for risk mitigating, while the other half are for speculation purpose,[3] which is a second motivation for derivative usage completely ruled out by previous researches. For insurers that use derivatives for speculation, they may rely more on reinsurance for risk controlling. On the other hand, for insurers that hold hedging positions in derivatives, less reinsurance coverage may be required to maintain the same level of risk exposure. Mixing all firms together clearly can cancel out any impacts that may exist. ii) Reinsurance variable is treated as exogenous in both papers. The degree of reinsurance coverage should be determined by a firm's specific risk features, including its risk exposure, as discussed in the insurance literature. In addition to the traditional financial statement variables, the alternative risk hedging for reinsurance, namely derivative hedging, may also affect the primary insurers' reliance on reinsurance. This aspect, which is one focus of this study, has been largely ignored in the existing literature. We believe that this paper can fill up the gap in the link, and present a complete picture of PC insurers' risk hedging behavior.

3 Model

We study the hedging decision of an insurance company using both reinsurance and derivatives in a two period setup. At time t=0, the insurance company starts with internal capital ω, which is carried forward from previous periods of operation. It decides to underwrite loss coverage $\tilde{L}$,

[3] We will discuss this in detail in the data section.

with $E[\tilde{L}] = L$ and $Var[\tilde{L}] = L^2\sigma_L^2$, by charging a premium loading equals to δ_1. In other words, the insurance company collects premium of $(1+\delta_1)L$ from underwriting activity. At the same time, the insurer chooses to cede α share of the assumed loss to a reinsurer, who in turn charges a premium equals to $\alpha(1+\delta_2)L$, where δ_2 is the premium loading charged by the reinsurer. As a result, the insurance company retains $(1-\alpha)\tilde{L}$ of loss on its book.

Meanwhile, the insurer can invest its asset in the capital market to generate investment income. For simplicity, We assume that the capital market investment return follows a normal distribution $\tilde{R}_I \sim N(\mu_I, \sigma_I^2)$, and that it is not correlated with the loss distribution. The insurance company can choose to hedge fraction h of its total asset using derivative tools, which generates a constant return $\tilde{R}_h \rightarrow \mu_h$ with probability equals to one, and $\mu_h >= 0$ by definition. Since risky asset should carry a risk premium, we would expect $\mu_I > \mu_h$. To be more specific, define V_0 as the total amount of asset available for investment, where

$$V_0 = \omega + (1+\sigma_1)L - \alpha(1+\delta_2)L \tag{1}$$

among which hV_0 is hedged using derivative tools.

Throughout the rest of the model, we assume that the insurance company's goal is to achieve mean-variance efficient. In other words, it tries to maximize its expected return holding variance constant at certain level. This is an over-simplified setup of the real world scenario, but it serves the purpose to capture the conflicting forces in the decision making process, namely the profitability and stability of the insurance company. The insurance company can increase its profitability in one of the following two ways: be more aggressive in the risky asset investment, or underwrite more loss coverage to gain the premium loading. The by-product of either of these two methods is the increase in company portfolio volatility, which may in turn increase the risk of insolvency. We try to solve in this simple model the optimal combination of usage of reinsurance and derivative tools to hedge the portfolio volatility, and at the same time maximize the profitability of the insurance company.

3.1 Case 1: Costless Hedging

When hedging is costless, after hedging hV_0 of the asset using derivatives, the insurance company has $(1-h)V_0$ left to invest in the capital market. In total, the investment activity generates expected return:

$$E[(1-h)V_0\tilde{R}_I + hV_0\tilde{R}_h] = (1-h)V_0\mu_I + hV_0\mu_h \tag{2}$$

and variance equals to:

$$Var[(1-h)V_0\tilde{R}_I + hV_0\tilde{R}_h] = (1-h)^2V_0^2\sigma_I^2 \tag{3}$$

On the other hand, the expected return of the underwriting operation is

$$E[(1+\delta_1)L - (1-\alpha)\tilde{L} - \alpha(1+\delta_2)L] = (\delta_1 - \alpha\delta_2)L \tag{4}$$

and the variance of underwriting activity equals to:

$$Var[(1-\alpha)\tilde{L}] = (1-\alpha)^2 L^2 \sigma_L^2 \tag{5}$$

Therefore, the optimization problem of the insurance company can be expressed as:

$$Max_{\alpha,h} E[U(\cdot)] \equiv (1-h)V_0\mu_I + hV_0\mu_h + (\delta_1 - \alpha\delta_2)L - \frac{b}{2}[(1-h)^2 V_0^2 \sigma_I^2 + (1-\alpha)^2 L^2 \sigma_L^2] \tag{6}$$

where the positive coefficient b measures the degree of aversion of volatility. Taking first order derivative with respect to h, we get $\partial E[U(\cdot)]/\partial h = 0$

$$\Rightarrow -V_0\mu_I + V_0\mu_h - \frac{b}{2}[2(1-h)(-1)V_0^2\sigma_I^2] = 0 \tag{7}$$

$$\Rightarrow 1 - h = \frac{\mu_I - \mu_h}{bV_0\sigma_I^2} \tag{8}$$

Taking first order derivative with respect to α, we get $\partial E[U(\cdot)]/\partial \alpha = 0$

$$\Rightarrow -(1-h)(1+\delta_2)L\mu_I - h(1+\delta_2)L\mu_h - \delta_2 L + b[(1-h)^2 V_0(1+\delta_2)L\sigma_I^2 + (1-\alpha)L^2\sigma_L^2] = 0 \tag{9}$$

$$\Rightarrow \alpha^* = 1 - \frac{(1+\delta_2)\mu_h + \delta_2}{bL\sigma_L^2} \tag{10}$$

Plug α^* back into equation 8, we get

$$h^* = 1 - \frac{(\mu_I - \mu_h)\sigma_L^2}{b\sigma_I^2\sigma_L^2[\omega + (\delta_1 - \delta_2)L] + \sigma_I^2[(1+\delta_2)^2\mu_h + (1+\delta_2)\delta_2])} \tag{11}$$

Some stylized facts from the optimization solution. First we study the relationship between the amount of reinsurance usage, α, and the level of derivative hedging, h.

$$\frac{\partial h}{\partial \alpha} = -\frac{(\mu_I - \mu_h)(1+\delta_2)L}{bV_0^2\sigma_I^2} < 0 \tag{12}$$

since by definition $\mu_I > \mu_h$. In other words, there is a substitution effect between the usage of reinsurance and derivative hedging. When the insurance company increases the amount of risk ceded to the reinsurer, less amount of derivative hedging on asset is necessary in order to maintain the same level of volatility on the company portfolio. And vice versa. Since the goal of the insurance company is to maximize the expected investment income holding volatility of the whole company constant, and that investing in risky asset generates a higher expected return than the hedged positions, the reduction of volatility of underwriting activity due to increase in reinsurance coverage α releases the company's capital from the hedged positions into the risky investment class, hence lowers the hedge ratio h.

More elaboration on the optimal reinsurance ratio α^*:

- $\frac{\partial \alpha^*}{\partial \delta_2} = -\frac{1+\mu_h}{bL\sigma_L^2} < 0$. When reinsurance becomes more expensive, the insurance company chooses to cede less risk.

- $\frac{\partial \alpha^*}{\partial \mu_h} = -\frac{(1+\delta_2)}{bL\sigma_L^2} < 0$. When hedging generates higher return, in other words, the insurance company sacrifices less return for not investing in the risky asset, it will use less reinsurance.

- $\frac{\partial \alpha^*}{\partial b} = \frac{(1+\delta_2)\mu_h+\delta_2}{b^2L\sigma_L^2} > 0$. The more risk averse the insurance company is, the more reinsurance coverage it will use.

- $\frac{\partial \alpha^*}{\partial L} = \frac{(1+\delta_2)\mu_h+\delta_2}{bL^2\sigma_L^2} > 0$. The higher the expected amount of loss, the more reinsurance the insurance company will use.

- $\frac{\partial \alpha^*}{\partial \sigma_L^2} = \frac{(1+\delta_2)\mu_h+\delta_2}{bL\sigma_L^4} > 0$. The more volatile the undertaken loss is, the more reinsurance the insurance company will use.

More elaboration on the optimal hedging ratio h^*. Although the sign of $(\delta_1 - \delta_2)$ is undetermined, we assume that with reasonable initial capital ω to begin with, $\omega + (\delta_1 - \delta_2)L > 0$. Therefore, $A \equiv \omega + (\delta_1 - \delta_2)L + ((1+\delta_2)^2\mu_h + (1+\delta_2)\delta_2)/(b\sigma_L^2)$ is also greater than 0.

- $\frac{\partial h^*}{\partial \mu_I} = -\frac{1}{b\sigma_I^2 A} < 0$. The higher the expected return from investing in risky assets holding μ_h constant, the more volatility the insurance company is willing to take in its investment portfolio by lowering the hedge ratio, in exchange for high expected return in the risky asset class.

- $\frac{\partial h^*}{\partial \mu_h} = \frac{b\sigma_I^2 A+(\mu_I-\mu_h)(1+\delta_2)^2\sigma_I^2/\sigma_L^2}{(b\sigma_I^2 A)^2} > 0$. The insurance company is willing to hedge more when opportunity cost of hedging asset is lower, since higher μ_h closes up the gap between the returns of risky asset and hedged positions.

- $\frac{\partial h^*}{\partial \sigma_I^2} = \frac{\mu_I-\mu_h}{bA\sigma_I^4} > 0$. The more volatile the risky asset, the more the insurance company will choose to hedge.

- $\frac{\partial h^*}{\partial \sigma_L^2} = -(\mu_I - \mu_h)[(1+\delta_2)\delta_2 + (1+\delta_2)^2\mu_h]/(b\sigma_I B)^2 < 0$. *I don't have a good explanation for this relationship. It could be that since volatility in loss coverage increases, reinsurance seems to be a better hedging tool for that type of risk than derivatives. As α increases, the fraction of volatility that needs to be controlled using derivatives goes down, and therefore h goes down.*

- $\frac{\partial h^*}{\partial b} = (\mu_I - \mu_h)(b\sigma_I^2 A)^{-2}[\sigma_I^2(\omega + (\delta_1 - \delta_2)L] > 0$. The more risk averse the insurance company is, the more fraction of asset will be hedged.

3.2 Case 2: Costly Hedging

Assume now that there exists a proportional cost of hedging. For each dollar hedged, the insurance company pays γ dollar to set up the contract. Under this scenario, after hedging hV_0 amount of asset, the insurance company is left with $(1-(1+\gamma)h)V_0$ to invest in the risky asset class. With this change in mind, the new optimization problem of the insurance company is

$$Max_{\alpha,h}E[U(\cdot)] \equiv (1-(1+\gamma)h)V_0\mu_I + hV_0\mu_h + (\delta_1 - \alpha\delta_2)L - \frac{b}{2}[(1-(1+\gamma)h)^2V_0^2\sigma_I^2 + (1-\alpha)^2L^2\sigma_L^2] \tag{13}$$

Take first order derivative against h, we get $\partial E[U(\cdot)]/\partial h = 0$

$$\Rightarrow -(1+\gamma)V_0\mu_I + V_0\mu_h - \frac{b}{2}[2(1-(1+\gamma)h)(-(1+\gamma))V_0^2\sigma_I^2] = 0 \tag{14}$$

$$\Rightarrow 1-(1+\gamma)h = \frac{(1+\gamma)\mu_I - \mu_h}{b(1+\gamma)V_0\sigma_I^2} \tag{15}$$

Take first order derivative against α, we get $\partial E[U(\cdot)]/\partial \alpha = 0$

$$\Rightarrow -(1-(1+\gamma)h)(1+\delta_2)L\mu_I - h(1+\delta_2)L\mu_h - \delta_2 L + b[(1-(1+\gamma)h)^2V_0(1+\delta_2)L\sigma_I^2 + (1-\alpha)L^2\sigma_L^2] = 0 \tag{16}$$

$$\Rightarrow \alpha^* = 1 - \frac{(1+\delta_2)\mu_h + (1+\gamma)\delta_2}{b(1+\gamma)L\sigma_L^2} \tag{17}$$

Plug α^* back into equation 15, we get

$$h^* = \frac{1}{1+\gamma} - \frac{(1+\gamma)\mu_I - \mu_h}{b(1+\gamma)^2\sigma_I^2[\omega + (\delta_1-\delta_2)L + \frac{(1+\delta_2)^2\mu_h + (1+\gamma)(1+\delta_2)\delta_2}{b(1+\gamma)\sigma_L^2}]} \tag{18}$$

Focusing on the relationship between derivative usage h and reinsurance ceded α when hedging is costly:

$$\frac{\partial h}{\partial \alpha} = -\frac{((1+\gamma)\mu_I - \mu_h)(1+\delta_2)L}{b(1+\gamma)^2V_0^2\sigma_I^2} < 0 \tag{19}$$

since by definition $\mu_I > \mu_h$ and $\gamma \geq 0$. Same logic under the costless hedging scenario, when larger fraction of the portfolio volatility is mitigated using reinsurance, the insurance company can free more capital from the hedging positions into more profitable risky asset class, which supports the substitution effect between these two options of volatility control mechanisms.

3.3 Case 3: Correlation Between Asset and Liability

Now we will extend the model on the basis of Case 2, where hedging is costly, into a more realistic scenario, under which the investment return on the asset side is correlated with the underwriting loss distribution. Assume ρ is the correlation coefficient. The new optimization problem facing the insurance company is now

$$Max_{\alpha,h}E[U(\cdot)] \equiv E[P] - \frac{b}{2}Var[P] \tag{20}$$

where

$$E[P] = (1-(1+\gamma)h)V_0\mu_I + hV_0\mu_h + (\delta_1 - \alpha\delta_2)L \quad and \tag{21}$$

$$Var[P] = (1-(1+\gamma)h)^2V_0^2\sigma_I^2 + (1-\alpha)^2L^2\sigma_L^2 + 2(1-(1+\gamma)h)(1-\alpha)V_0L\rho\sigma_I\sigma_L \tag{22}$$

Take first order derivative with respect to h, we get $\partial E[U(\cdot)]/\partial h = 0$

$$\Rightarrow 1-(1+\gamma)h = \frac{(1+\gamma)\mu_I - \mu_h - b(1+\gamma)(1-\alpha)L\rho\sigma_I\sigma_L}{b(1+\gamma)V\sigma_I^2} \tag{23}$$

For notational brevity, denote $B \equiv (1+\gamma)\mu_I - \mu_h - b(1+\gamma)(1-\alpha)L\rho\sigma_I\sigma_L$. Again, to study the relationship between hedge ratio h and reinsurance usage α:

$$\Rightarrow \frac{\partial h}{\partial \alpha} = -\frac{B(1+\delta_2)L}{b(1+\gamma)^2\sigma_I^2V_0^2} \tag{24}$$

The sign of this relationship is undetermined. Given all the other terms are positive, the sign is determined by B. Denote $\bar{\rho} = \frac{(1+\gamma)\mu_I-\mu_h}{b(1+\gamma)(1-\alpha)L\sigma_I\sigma_L}$. When $\rho \in [-1,\bar{\rho})$, we get $B > 0$, and hence $\frac{\partial h}{\partial \alpha} < 0$, which supports the substitution hypothesis. When $\rho \in (\bar{\rho}, 1]$, we get $\frac{\partial h}{\partial \alpha} > 0$. To explain the economical rational behind the second range of relationship between h and α: first notice that the cut off point $\bar{\rho}$ is positive, since $\mu_I > \mu_h$ and that $\gamma \geq 0$. When $\rho > \bar{\rho}$, in other words, when asset and liability distributions are sufficiently positively correlated, there exists a natural asset-liability value hedging. That is, when the realized loss is high, due to the positive correlation, we would expect to see high realized return on the risky investment as well, and hence compensates for the loss in the underwriting arm. To relate to the reinsurance and derivatives hedging decision, when the insurance company reduces the reinsurance coverage α, the increased risk of underwriting liability can be naturally hedged by increasing the exposure in risky asset, given that they are sufficiently positively correlated, and hence lowers the hedging ratio h. Therefore, when ρ exceeds certain positive threshold, we would expect to see h and α to be positively correlated.

4 Data and Variable Construction

The companies included in this study are property and casualty insurance companies in the U.S. market. We study the hedging behavior of these companies between year 2000 and 2005.[4] To our

[4]NAIC starts to provide digitally recorded derivative trading data in 2000.

knowledge, this is the most comprehensive and updated study on insurance companies' hedging behavior, since the existing literatures all use the same data from annual report of 1994. Following approaches by previous studies,[5] firm-level data are used in this study instead of the group-level data. Although many of the firms in the sample belong to common holding groups, analyzing them at aggregate level eliminates a lot of the interesting decision making mechanism that we would like to explore. For example, if within a group, the reinsurers provide reinsurance to primary insurers, the group will be appear to be neutral on average regarding the demand for reinsurance coverage. However, it is not the case at firm-level. As a result, we will focus on the firm-level analysis in the rest of the paper.

All accounting related data are obtained from NAIC annual statement, and credit information is obtained from A.M. Best's Key Rating Guide. Risk retention groups are excluded from this study, since their unique features determine the hedging behavior to be quite different from majority of the companies in the market.[6] We further excluded firms whose asset, total premium written or policyholders surplus are negative, as these companies are either in the process of liquidation or merges and acquisition, and hence do not engage in normal risk management activities. Winsor censoring is also performed to exclude firms with extreme risk exposures or asset composition that may distort the overall sample results. In addition, we filter out micro-size firms, whose assets are less than \$10 million. In the end, we record over 2000 unique insurers in the observation period, which sums to around 9000 firm-year samples.

Hedging Variables

Level of reinsurance usage is measured as the percentage of reinsurance premium ceded over total premium written.[7] It represents how much of the underwriting risk is layered off by primary PC insurers to their reinsurance providers. If this ratio is zero, primary insurers retain 100% of the loss exposure on their book. And if it is one, primary insurers are completely immune from underwriting loss risks.

Derivative hedging is measured using both the participation indicator as well as volume variables. All derivative transaction data are obtained from Schedule DB of PC insurers' annual statement to NAIC. In addition to the description of the derivative traded, the insurer also self-report the purpose of this particular transaction: whether it is for hedging or other purpose, such as income generating. An insurer is considered a derivative hedger for year t if it reports any derivative trading activities during that year, and states at least part of these derivative positions are for hedging purpose. If stated otherwise, the derivative user will be classified as

[5] Cummins et al. (1997) (2001)

[6] Risk retention groups are set up in order to write liability exposures from other members of the same insurance group. They are restricted to liability risks only, and are not permitted to underwrite business from outside the group.

[7] Total premium written includes direct premium written and reinsurance premium assumed.

derivative speculator.[8] In total, there are 237 firm-year derivative hedgers, represented by 83 unique insurers. And 289 firm-year derivative speculators, represented by 102 unique firms. We use both notional amount and market value of derivative positions held at year end on insurers' annual statement to measure the volume engaged, both normalized by total asset value of the firm. Although notional amount for certain types of derivatives traded are not reported, we use information such as number of contracts traded and strike price to back out the approximation for notional value for these contracts.[9] While notional amount provides an intuitive snapshot of firms' usage of derivative hedging, market value shows exactly how much these positions are worth in economical sense. Combining these two will give us an extensive view of the derivative hedging decisions.

Independent Variables

Exposure in Catastrophic Risk. We model each PC insurance company's exposure in catastrophic risk with the following two variables: i) percentage of total premium written in earthquake line of business; ii) percentage of total premium written in catastrophes (earthquake, hurricane and tornado) affected states, including Alabama, California, Florida, Georgia, Hawaii, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina and Texas. In addition, we also include the variable measuring the percentage of premium written in long tail business lines.[10] Although slightly different in nature from the above two catastrophic risk measurements, once claim made, the absolute amount paid out from these long tail policies can have huge impact on firms' capital level as well. It is expected that the higher the exposure to these catastrophic risks one has, the more coverage of reinsurance hedging it will seek. Herfindahl indexes on premium written by lines of business and by states are also included to measure the diversification of a given company. If a firm is well-diversified in the lines of business and states it underwrites (low line of business herfindahl index and geographical herfindahl index), the natural hedge among lines and states will crowd out the demand for reinsurance to certain degree.

Reinsurance Cost and Sustainability. We construct a set of variables to measure the level of asymmetric information between the reinsurance purchaser and provider.[11] Garven and Grace (2007) argue that if there exists a long term contractual relationship between the primary insurer and the reinsurance provider, the price for reinsurance should be cheaper as there is less asymmetric information suffered by the outsider. And hence, we would expect to see more rein-

[8] Since any insurance company can use derivative for hedging and income generating at the same time, there is overlap in the derivative hedgers and speculators.

[9] Notional amount for equity options are approximated as number of contracts$\times$strike price$\times$100. Notional amount for bond options are approximated as number of contracts$\times$par value per contract.

[10] Long-tail business lines include farmowners multiple peril, homeowners multiple peril, commercial multiple peril, other liability occurrence and claims made. The empirical results are robust to other compositions of long-tail lines of business.

[11] All relevant data on reinsurance are obtained from Schedule F - Part 3 of NAIC Annual Report.

surance usage for firms with long term relationship with their reinsurers holding everything else constant. We model the reinsurance sustainability in year t as the percentage of premium ceded to reinsurers that underwrites reinsurance in year $t-2$ and $t-1$. Reinsurance herfindahl index is also included to measure the diversification of reinsurance coverage purchased by a given primary insurer. With a well-diversified source of reinsurance coverage, the primary insurer may be safer from payment default from reinsurer, and demand less reinsurance coverage. However, with concentrated reinsurance providers, the reduced level of asymmetric information may encourage the primary insurer to purchase more reinsurance. The net effect is uncertain. Last but not least, the cost of reinsurance coverage should directly affect the demand of reinsurance by primary insurers. Though it is impossible for us to measure the premium loading charged by reinsurance providers, we estimate the cost of reinsurance as premium ceded normalized by loss incurred in the same year.[12]

Credit Ratings. Credit rating is an important consideration when firms choose their investment, capital and hedging structures. For example, Graham and Harvey (2001) conclude from the survey to CFOs that credit rating is a crucial concern when deciding on firms' leverage level. Impacts on firms' stock and bond returns due to changes in credit ratings are also discussed extensively (Hand et al. (1992), Dichev and Piotroski (2001)). One recent research by Kisgen (2006) provides further evidence of the impact of credit rating on firms' capital structure decisions. He claims that when firms are at the edge of getting upgraded or downgraded, they tend to lower the leverage ratio to benefit from higher credit rating, or avoid the cost of depressed credit rating respectively.

For financial institutions such as insurance industry, where credit rating is equivalent to the reputation and quality of the services provided, it is even more central to the the firm's financial planning decisions. Zurich, for example, explicitly defines its target level of risk-based capital as "...the capital needed to protect the Groups policyholders against the worst-case loss (which the Group calibrates according to its financial strength target of AA)" (2006:55). And this is not an isolated phenomenon in the insurance industry. Based on the above observations, we include the following variables to model the impact of credit ratings on PC insurers hedging strategies in this paper: i) indicators for whether the firm got downgraded from previous year; ii) indicators for firms near a credit downgrade, which is approximated by whether it is under negative watch by the rating agency; and iii) the firms' current level of credit ratings. We transform the letter credit rating into a cardinal scale, with "A++" corresponding to 1, "A+" to 2, and etc.[13] Firms whose credit rating is not assigned explicitly by Best's are naturally excluded. Following the practice of Epermanis and Harrington (2006), we also excluded small number of firms whose credit ratings are below "C-", as these firms are most likely not conducting normal underwriting business, and

[12] Loss incurred (t) = Loss paid (t) + Reserve (t) - Reserve (t-1).

[13] Other cardinal scales are also tested empirically, and results are robust to the choices of transformation.

hence have no need for hedging protections.

Asset-Liability Management. Asset liability duration match is one key goal for PC insurers' risk management. Asset duration, D_A, is estimated by the value weighted average of maturity class. We apply Taylor's separation method to calculate the liability duration D_L. The difference between these two is the asset liability duration gap of a particular insurer, $D_{gap} = D_A - D_L$.[14] And we expect this variable to be positively correlated with the level of derivative hedging. In addition, we include asset turnover ratio variable, defined as the sum of investment proceeds and cost of investment acquired over total asset. Firms that are active in asset acquisition and selling display more aggressive investment patterns, and are expected to be savvier in the combination of financial instruments for hedging purpose.

Other explanatory variables on the firms' asset compositions, such as percentage of asset held in stocks, bonds, risky bonds, real estates, mortgages, and percentage of assets invested in foreign bonds and stocks are included as control variables as well. It is believed that the higher percentage of assets invested in safe asset class, such as bonds (government bonds in particular) is associated with lower level of hedging. And vice versa for high risk investments, such as stocks and foreign assets. Here it is worthwhile to clarify the definition of *risky bond.* We define risky bond as the percentage of financial asset invested in non-government sponsored bonds. Non-government sponsored bonds can be defined in one of the following three levels, from tight to loose: 1) bonds issued by agents other than governments, 2) bonds issued by agents other than the governments and states, territories and possessions, and 3) bonds issued by agents other than 1), 2) and political subdivisions of 2). We follow the definition of case 1) in the empirical analysis, as only the government backed bonds are truly risk free based on the observation in the recent sub-prime crisis induced credit crunch and bond auction failure.[15] Following the same argument, investment class alone does not serve as a good indication of the credit quality of the issuers, as a lot of the structural products that failed in the sub-prime crisis were actually AAA rated. Therefore, we will model risky bond as in case 1) rather than the usual investment class 3-6 proposed by Best's Rating.

Loss and Surplus Development. The stability of a PC insurer's liability development with respect to its surplus growth influences the hedging decisions. If the loss development has been relatively predictable and the liability growth being slow relative to the surplus accumulation, the insurance company may choose to opt out certain hedging coverage, since its existing capital level can provide a thicker financial cushion than before. We model the loss stability using a

[14] D_A is an approximation for duration. We calculate it as the value-weighted average maturity of bonds holdings reported in Schedule D - Part 1A of PC insurers' annual report. To estimate D_L, we use incurred loss from Schedule P of annual statement to project the total incurred loss, and calculate the duration for outstanding liability. Please refer to Taylor (2000) chapter 3 for detailed methodology description.

[15] WSJ (2008).

three-year moving volatility of loss ratio and combined ratio. Liability development with respect to surplus is measured as a ratio of direct premium written over policyholders' surplus. Low ratio is associated with low net new liability assumed, and hence does not require additional hedging coverage. Surplus growth is simply modeled as percentage changes in policyholders' surplus with respect to previous year's level. The higher the growth rate, the more abundant the capital protection for financial distress, and lowers the demand for hedging.

Last but not least, insurance companies will refer to these loss and surplus factors when deciding how much to hedge only when these measurements are reliable. We use the reserving error to estimate how close the firms' projections are to the real outcome, which is a ratio of one year total loss development over most recent year's total incurred losses and loss adjustment expenses.[16]

Other Firm-Specific Variables. In addition to the above explanatory variables, we also control the firms in this study with the following firm features: i) size of the firm is measured by log(total assets); ii) profitability of the firm is approximated as return on equity; iii) liquidity is calculated as the percentage of short-term asset[17] over total asset; iv) leverage is measured as the ratio of total liabilities over total policyholders' surplus on the balance sheet; v) indicating variables for a firm's organization forms, such as whether it is publicly traded or privately held, whether it is a stock or a mutual company, and etc.

5 Structural Model

We model the hedging decision of an insurance company under a simultaneous equations set up. In the first equation, the level of reinsurance usage is determined by the availability of derivative coverage, on top of various other reinsurance related determinants. Similarly, the decision and degree of derivative hedging is influenced by how much reinsurance protection the underlying firm has, together with derivative hedging related factors. Since the two hedging variables clearly are inter dependent, simple OLS analysis will return biased estimations. In addition, as the firms in the sample are quite different from one another, in terms of organization form, asset composition, loss development and etc, it is reasonable to believe that the error terms are heteroskedastic. As a result, we will estimate this structural model using GMM. We express the system of equations as the following:

[16] Data regarding loss development are obtained from Schedule P of NAIC Annual Report.

[17] Short-term asset is the summation of bonds, stocks, cash and cash equivalent on the balance sheet.

Reinsurance usage:

$$Reinsurance = f(Derivative, CATExposure, ReSustainability, CreditRating, \\ LossSurplusDevelopment, Others) + \varepsilon_1 \tag{25}$$

Derivative hedging:

$$Derivative = g(Reinsurance, CATExposure, CreditRating, \\ AssestLiabilityManagement, Others) + \varepsilon_2 \tag{26}$$

where *Derivative* variable in both equation can refer to either participation dummy or volume variables, which is measured by notional amount or market value of the derivative positions.

One may argue the endogeneity problem of other independent variables for this particular study. In general, it is quite likely that an insurer's choice of what policies to write, how much to borrow, how to invest and various other financial decisions are determined by its hedging pattern, namely the level of reinsurance and derivative hedging. However, in our study, we try to avoid this potential endogeneity problem in the following way: other than the contemporaneous reinsurance and hedging variables for year t, we use lagged value from previous year $t-1$ for all the other variables. In this manner, we guarantee that all the other explanatory variables are predetermined at time t, and should impose no correlation with subsequent error terms in the structural model. One exception is the variable which measures the price charged for reinsurance coverage. The lagged value for reinsurance price appears to be endogenous when estimating reinsurance usage by an insurer using difference-in-Sargan test. Hence we treat it differently as an endogenous variable. To summarize, our structural model has three endogenous variables, namely reinsurance usage, derivative hedging and reinsurance price. All the other predetermined variables are used as instruments in the structural estimation. Appendix A shows part of the endogeneity test performed on the predetermined variables. After controlling endogeneity, the Hansen J test result indeed proves the validity of the instruments. Based on this result, we treat the remaining predetermined variables with confidence as exogenous in the remaining analysis.

To see why the system of equations is identified. First of all, we know the number of endogenous variable included in either equation is less or equal to three. In addition, the number of excluded instruments for reinsurance equation equals to the number of variables that belong to the category of asset and liability management, which is greater than two. Similarly, the number of excluded instruments for the derivative hedging equation is also greater than two. Since the number of endogenous variables in either equation is smaller than the number of excluded instrumental variables, we believe that this structure is indeed identified.

Reinsurance in this model is a continuous variable. Derivative participation and volume, in contrast, are limited variables. Given the fact that the participation of derivative hedging is a dichotomous variable, which takes value either zero or one, it should be modeled using Probit method. On the other hand, for studying the censored variable such as volume of derivative hedging, Tobit analysis is the generally used. Standard Tobit model, however, has been under criticism for modeling this type of censored variable, under which the signs for the variables from the volume decision analysis are forced to be the same as the participation decision. To correct this mis-specification, previous studies turn to Cragg's (1971) generalized Tobit model, which allows the limited participation variable to be estimated separately from the volume variable.[18]

6 Empirical Results

Table 1 provides the summary statistics of key variables used in this study. We report three sets of statistics: full sample, derivative hedgers and non-hedgers sub-sample. Panel A lists the means of the hedging variables. Level of derivative hedging is represented by notional amount and market value of derivative positions. For derivative hedgers, the economical value of their hedging position counts for about 2.3 percent of total asset. It is obvious that the notional amount of the hedging positions are much larger than ones represented in market value. This difference can be explained using the following analogy: an out-of-the money option is worth close to nothing in economical value, but is worth strike price in notional value. The other option of hedging, reinsurance, is measured as a percentage of total premium ceded to reinsurers. In addition, we show the percentage of total premium ceded to unaffiliated reinsurers. Panel B lists the means of independent variables. In addition, we show the t-test results on the variables of interest for derivative hedgers versus non-hedgers. We see that for derivative hedgers, most of the explanatory variables are significantly different from the firms in full sample.

6.1 Reinsurance Hedging

As described in equation (25), reinsurance usage by a typical PC insurance company is determined by its exposure in underwriting shocks due to catastrophes (either by line of business or geographical exposure), sustainability of its reinsurance contracts, impact from the credit rating agencies, loss and surplus development, other firm characteristics such as size, and last but not least, the coverage from derivative hedging.

Table 2 shows the results of two stage GMM on reinsurance usage, using derivative hedging dummy as a measure of alternative hedging options. Across three different sets of models, derivative hedgers are found to use much less reinsurance coverage, holding everything else constant. Similarly, Table 3 and Table 4 present the impact of reinsurance usage by market value

[18] See Colquitt and Hoyt (1997), Cummins et al. (2001) for detailed discussion.

and notional amount of derivative hedging positions respectively, along with all other explanatory variables. We observe strong negative impact from the volume of derivative hedging on the reinsurance usage across models when measured by market value of the hedging positions. Notional amount, however, presents less strong evidence of the impact of derivative hedging on the choice of reinsurance coverage. This difference may be due to the nature of the two difference measures of derivative volume, as market value provides a more realistic estimate of the real value of the underlying hedging position to a given firm, while notional amount does not necessarily reflect the true effect. To summarize, the derivative hedging is found to be negatively correlated with the reinsurance usage when measured by both participation dummy and volume variables in most cases. This finding provides partial evidence that there exist substitution effect in the two options of hedging: when firms participate in more derivative hedging, they need to rely less on reinsurance for risk management.

Firms with high CAT exposure use more reinsurance coverage. Most of the proxies for CAT exposures display positive impact on the level of reinsurance engaged across models. When an insurer has high percentage of total premium written in catastrophe-prone states, it chooses to cede more premium to reinsurance companies. Similarly, when an insurer displays high exposure in long-tail property-liability (PL) line of business, it chooses to rely more on reinsurance hedging against the underwriting volatility in general. The traditional measure of catastrophic exposure, the percentage of premium written in earthquake line of business, does not show strong effect across different measures and models, as part of its effect is probably already reflected in other measures of catastrophic exposure.

Results of diversification with respect to line of business and geographical exposure are quite surprising. Firms that are less diversified across states and lines of business tend to use less reinsurance protection. This may be explained by the fact that many of the firms in this sample are actually small regional insurance companies, with relatively simple composition of lines of business. Limited by their risk exposure, they have no strong incentive to pay for reinsurance protection.

Price of reinsurance is definitely the key factor determining the reinsurance usage. Although we can not measure the premium loading charged by reinsurers directly, we use premium charged for per unit of loss incurred as an approximation. Contrary to our original belief, the higher the premium charged by reinsurers for a unit of loss incurred, the more reliance the insurers have for reinsurance protection. As we pointed out earlier, this "anomaly" can be explained by the endogeneity of the reinsurance price factor. If an insurer is more likely to experience loss shocks, it is more willing to seek protection from reinsurers. The reinsurers, knowing that the these are the more risky policyholders, charge a higher premium loading for its own profitability. On the other hand, when estimating cost of reinsurance using the reinsurance sustainability variable, we observe strong positive impact on firms' reinsurance usage across Table 2 to 4. This is consistent with Garven and Grace (2007)'s argument that if a primary insurance company has long term relationship with its reinsurance providers, the asymmetric information component in the reinsurance premium loading goes down. Hence reinsurance price should be cheaper for a returning customer than a new one given the same risk exposure. As a result, the primary insurance company will use more reinsurance coverage when price goes down. A third proxy for reinsurance cost we use is the herfindahl index for reinsurance coverage. Consistent with the sustainability explanation, when primary insurers purchase reinsurance coverage from concentrated reinsurers, it is highly likely that the level of asymmetric information between these two is low, and therefore the low premium loading and high demand for reinsurance.

Credit rating exerts strong impact on firms' reinsurance hedging decisions. Firms with high credit ratings on average use more reinsurance coverage than firms with low credit ratings. These high credit rating firms are associated with high franchise value and reputation cost, and therefore are expected to engage in more conservative reinsurance hedging to secure the value. What's more, firms that are under negative watch from Best's, or got downgraded in the previous year engage in more reinsurance coverage compared to other firms. Based on results from Table 2 to 4, both the credit downgrade and negative watch dummy have strong positive impact on the usage of reinsurance. If a firm was downgraded in year $t-1$, as a percentage of total premium written, it will use around 4.9 percent more reinsurance in year t. A firm that is under negative credit watch will increase its usage of reinsurance by about the same level. This result may be driven by the motivation that the managers are trying to layer off underwriting risk from its balance sheet in order to rescue the firm from getting downgraded, or pull it back to the pre-downgraded level. This explanation is analogous to Kisgen (2006)'s findings where firms at the edge of credit rating change are found to lower the leverage ratio to either pump up the credit rating to a higher level or to rescue it from slipping downwards.

Surplus cushion also affects the insurers' reinsurance appetite. We observe in model 3 across Table 2 to Table 4 that DPW/PHS is strongly positively correlated with the reinsurance coverage. When a firm assumes high level of new liability relative to existing policyholders' surplus (high DPW/PHS), the surplus cushion is diluted with the newly assumed policies, and therefore requires more reinsurance hedging against adverse development. On the other hand, loss volatility also affects the reinsurance decision of the primary insurers. If a firm's loss ratio displays high volatility, the insurer is less certain about the loss claims it is going to face. As a result, it will have more incentive to purchase reinsurance protection to layer off the risk exposure. A third measure of sufficiency of surplus cushion is the insurer's loss development. When a firm displays high growth in loss development in current year compared to previous years', it will naturally seek more reinsurance coverage. And the results across tables show strong support. The last capital development indicator, changes in PHS, does not show any impact on the reinsurance choices.

Consistent with previous research on reinsurance usage, we discover firms publicly traded firms with high liquidity tend to use less reinsurance, since their less likely to experience capital constraint due to loss shocks. However, results on the firms' leverage level are some what puzzling. One would expect insurer with high leverage ratio to seek more reinsurance protection. In our study, this is exactly the opposite. One explanation for the counter intuitive relationship is the endogenous risk appetite of a given firm. If a firm prefers to take on more risky policies to earn premium loading, naturally it would be willing to retain higher fraction of the risk on its book rather than giving up the underwriting profit to reinsurers.

6.2 Derivative Hedging

Derivative hedging participation is modeled using Probit analysis. And we study the derivative hedging volume (market value and notional amount) using Cragg's (1971) Tobit model. Like the reinsurance usage decision, derivative hedging behavior of an insurance firm is determined by its exposure in the CAT line of business or geographical allocation, potential pressure from the credit rating agencies, and firm specific variables representing size, profitability, liquidity and etc. Moreover, insurers' asset-liability composition should play an important role in deciding whether to use derivatives to hedge, and if so, how much to use. Last but not least, the alternative risk management option, in this case the level of reinsurance coverage, also comes into play in the derivative hedging decision.

Table 5 reports the second stage Probit regression result on the derivative hedging participation dummy. *Reinsurance Usage* shows strong and negative correlation with the derivative hedging dummy across three models tested. Strong negative impact from reinsurance usage is also observed on market value and notional amount of derivative hedging positions as shown in Table 6 and Table 7. Since market value represents the economical value of the hedging position, it usually appears in much smaller scale than the notional amount, where the hypothetical value is shown without consideration of the probability of such position ever being exercised. As a result, the coefficients of Table 7 appear unanimously larger than the ones in Table 6. This observation provides the second half support for our hedging substitution hypothesis: when an insurer has high risk coverage from derivative hedging, it chooses to have lower reinsurance protection.

The two direct measures of CAT exposure of a firm, percentage of premium written in earthquake and catastrophe prone states, do not show significant impact on the decision of derivative hedging in two out of the three proxies for derivative participation, since their impact should be mostly exerted on the reinsurance coverage. Long tail policies, on the other hand, may require duration matching from the asset side as their payout are spread out over longer span of time by definition. Consistent with this logic, we observe positive correlation between derivative hedging and the firms' exposure in long tail lines of business in all three tables. And the level of concentration on the lines of business of a given firm continues to display some negative impact on the risk hedging decision of the company.

Similar to the reinsurance usage analysis, credit rating agency is also found to exert significant impact on an insurer's derivative hedging behavior. If an insurer is downgraded from previous year by Best's Rating, not only will it be more likely to use derivative hedging, it will use heavier volume as well. Management team tries to enhance a firm's credit outlook by more conservative risk management strategy and therefore use more derivative hedging. For publicly traded firms, this result can be further interpreted as an attempt to improve market value of its equity. For example, Nelson et al. (2005) record an annual outperformance of 4.3 percent by derivative hedging firms compared to non-hedgers. Although the market reward effect does not apply to privately-held companies, management team can still use derivative hedging as positive signals to investors and bondholders to compensate for the shadow imposed by credit downgrading.

The asset-liability management style of an insurer affects its risk exposure, and as a result influences the derivative hedging decision. As we discussed before, if a company is actively engaged in selling existing assets and acquiring new ones, it displays stronger risk appetite and savvier investment style. We would expect these firms to be more comfortable with the idea of hedging risk using derivative positions. And it is indeed the case shown by the variable *Turnover* across different models and measures of derivative hedging. Another important asset-liability management index is the duration gap between the two sides. The higher the duration gap is, the more vulnerable the firm's net worth is under adverse external risk movement, mainly interest rate fluctuation. We do observe such strong positive relationship across models measuring participation dummy and volume proxies. One more year in the duration gap increases the firm's probability of using derivative to hedge by around 8 percent, according to Table 5.

When majority of a company's assets are held in safe asset class, such as bond, it will require less coverage for credit default risk. To further classify the types among bonds, this result is mainly driven by guaranteed government. If an insurer has high percentage of its asset held in risky bond, bonds issued by agencies other than the government, it may need to hedge the position with derivative tools against default. We do not have direct link between the risky bond holding and corresponding derivative hedging targeting that specific risk in this study, but strong positive impact from risky bond holding to derivative hedging is indeed shown across models and proxies for derivative hedging.

Stock holdings, however, does not display strong influence on insurers derivative hedging decisions. First of all, the percentage of total asset invested in stocks in our sample of insurance firms is low compared to bond, 12 percent versus 60 percent. Secondly, we are not arguing that stock holding does not affect the derivative usage of the underlying company. It is very likely that a lot of the equity related derivative trading are reported as "income generating', which is not in the scope of this analysis. On the other hand, if a company has significant amount of asset locked in real estate,[19] its asset value should be fairly immune against any negative influence from external risk factors. Derivative hedging does not seem as necessary for these companies compared to the ones with high liquid asset component. Consistent with this logic, we see in our results that firms with high real estate holding in their asset portfolio are less likely to engage in derivative hedging. If they do, the volume used tends to be lower compared to the others.

Consistent with previous findings on derivative users' characteristics in finance and insurance literature, large firms are more likely to engage in derivative hedging, and they also tend to use more. In fact, as shown in the Table 8, around 70 percent of derivative hedgers fall into the top quartile of asset distribution. When double sort according to asset size and hedging volume,[20] we see high concentration of high volume users in largest asset quartile, which counts for about 75 percent when measured by either market value or notional amount. The second stage results across models in Table 5 to Table 7 provide further evidence. And last but not least, stock firms are more likely to participate in derivative hedging, and if they do so, they tend to use higher volume compared to mutual companies.

7 Conclusion

This paper studies the risk hedging decisions of PC insurance companies in the U.S. market. Under mean-variance efficiency framework, we predict the substitution effect between two common risk management options, reinsurance and derivative hedging. Since the two arms of an insurer's operation, namely underwriting and investment, shares the common pool of capital cushion, reduction in risk on one arm can lead to more risk appetite on the other.

We estimate the risk hedging behavior using firm level data between 2000 and 2005. To our best knowledge, this is the first comprehensive study over insurance companies' risk management decisions and the interaction within. In addition, we update the empirical research on derivative hedging of insurance companies by about ten years, from the 1994 data to more recent data after 2000. We show negative correlation between reinsurance and derivative hedging decisions after controlling for simultaneity and endogeneity, which serves as strong evidence for the substitution hypothesis.

Catastrophe exposure of a given insurer, in lines of business underwritten or geographical region covered, is found strongly affect the reinsurance coverage, its underwriting risk hedging

[19]As financial intermediaries, insurance companies hold most of asset in liquid form. When we refer to "significant amount", it means comparing to the average of the industry rather than absolute amount.

[20]Hedging volume is expressed as a ratio of total asset.

option. This impact does not affect the firm's derivative hedging decisions.

Credit rating agencies appear to play an important role in firm's risk hedging decision, affecting both the reinsurance usage and derivative hedging behavior. When a company is under adverse credit rating movement, either downgrading or negative watch by the rating agency, the management team tend to engage in more conservative risk hedging, hoping to cancel out the negative impact and pumping back the credit quality.

Another interesting finding is the significant impact of long term contractual relationship with reinsurers on PC insurers' reinsurance usage. Asymmetric information component in the pricing goes down as reinsurers get to have better estimate of primary insurers' risk exposure over the years. Therefore a reinsurer should charge lower premium for a returning customer than a new one. Lacking of direct measure of cost of reinsurance, the sustainability of primary insurers' reinsurance contracts serves as proxies. And we do find more reinsurance usage as the proxy price goes down.

Unique to the underwriting activity, the loss and surplus development has strong impact on the level of reinsurance required by a given insurer. And similarly, firms with high asset-liability management need demand more risk hedging through derivative trading.

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Table 1: **Summary Statistics**

Means and t-test results of full sample and hedging sub sample. Hedging variables include: *Reinsurance Usage*, total premium ceded divided by total premium written; and *Derivative Market and Notional Value*, market and notional amount of derivative position. *% Premium in Earthquake Line* is % of direct premium written (DPW) in earthquake line of business. *% Premium in Catastrophe States* is % of DPW in catastrophe-prone states. *% Premium in Property Liability Lines* is % of DPW in long-tail property-liability lines. *Herfindahl Line of Business, Geographical and Reinsurance* represent herfindahl index on line of business premium written, geographical premium written and reinsurance concentration respectively. *Reinsurance Sustainability* is % of premium ceded to reinsurers who provide reinsurance to the same company in all of previous three years. *Reinsurance Price* represents the price of reinsurance, calculated as premium ceded divided by loss incurred. *Best's Rating* is the credit rating obtained from Best's Report. *Credit Downgrade* and *Credit Negative Watch* are dummy variables that equal to 1 if a firm got downgraded in previous year or is under negative credit watch respectively. *Turnover* is the sum of investment proceeds and investment acquired divided by total assets. *Duration Gap* is the difference in duration of assets and liability. *% Bond & Risky Bond* are the % of firms total asset invested in bond and risky bond respectively. Same definition applies for *% Stock, Mortgage & Real Estate*. *% Foreign Asset* is % of total asset invested in countries other than U.S. and Canada. *DPW/PHS* is the ratio of direct premium written over policyholder surplus (PHS). Δ *PHS* is % change of PHS over previous year. *Loss Volatility* is three-year moving average volatility of loss ratio. *Loss Development* measures the reserving error as one year loss development divided by total loss of most recent year. *Size* is log(asset). *ROE* is return on equity. *Leverage* is calculated as total liability over PHS. *Liquidity* is the sum of bond, stock and cash holding over total asset. *Dummy Stock & Public* are dummy variables if the firm is organized in the stock form or publicly traded. *, **, *** means that the test statistic is significant at 10%, 5% and 1% respectively.

Variables	Full Sample	Hedgers	Non-Hedgers	Difference
N	9656	236	9420	
Derivative - Market Value	2.01E+05	6.85E+06	0	
Derivative - Notional Amount	2.81E+08	2.35E+08	0	
Reinsurance	0.3653	0.3315	0.3662	*
% Premium in Earthquake Line	0.0038	0.0022	0.0039	***
% Premium in Catastrophe States	0.3465	0.3258	0.3470	
% Premium in Property Liability Lines	0.3097	0.3282	0.3092	
Herfindahl - Line of Business	0.4559	0.3688	0.4581	***
Herfindahl - Geographical	0.4951	0.3485	0.4988	***
Herfindahl - Reinsurance	0.5977	0.4696	0.6017	***
Reinsurance Sustainability	0.4177	0.4585	0.4164	
Reinsurance Price	3.9441	1.3384	4.0235	*
Best's Rating	14.0088	13.3220	14.0279	**
Credit Downgrade	0.0736	0.1356	0.0719	***
Negative Credit Watch	0.0940	0.1610	0.0922	***
Turnover	0.7465	1.0503	0.7389	***
Duration Gap	3.1754	4.7030	3.1368	***
% Bond	0.5982	0.4883	0.6009	***
% Risky Bond	0.4340	0.4047	0.4347	***
% Stock	0.1234	0.2368	0.1205	***
% Mortgage	0.0017	0.0043	0.0017	***
% Real Estate	0.0080	0.0069	0.0081	
% Foreign Asset	0.0118	0.0196	0.0116	***
DPW/PHS	2.4570	2.1346	2.4651	***
$\triangle$ PHS	0.0773	0.0465	0.0780	**
Loss Volatility	11.9956	11.0182	12.0225	
Loss Development	-0.0054	0.0442	-0.0066	***
Size	19.0118	20.8582	18.9656	***
Return on Equity	0.0374	0.0301	0.0376	
Leverage	1.9446	2.1948	1.9383	***
Liquidity	0.8158	0.7886	0.8165	***
Dummy - Stock Firm	0.6982	0.8093	0.6952	***
Dummy - Public Firm	0.1013	0.0847	0.1018	

Table 2: **Reinsurance Hedging - with Derivative Dummy Variable**

Shows the coefficients and test statistics of two stage simultaneous regression: Reinsurance equation. Dependent variable, *Reinsurance Usage*, is total reinsurance premium ceded divided by total premium written. Among the independent variables, the hedging alternative variable, *Derivative Dummy*, equals to one if the firm uses derivatives to hedge. *% Premium in Earthquake Line* is % of direct premium written (DPW) in earthquake line of business. *% Premium in Catastrophe States* is % of DPW in catastrophe-prone states. *% Premium in Property Liability Lines* is % of DPW in long-tail property-liability lines. *Herfindahl Line of Business, Geographical and Reinsurance* represent herfindahl index on line of business premium written, geographical premium written and reinsurance concentration respectively. *Reinsurance Sustainability* is % of premium ceded to reinsurers who provide reinsurance to the same company in all of previous three years. *Reinsurance Price* represents the price of reinsurance, calculated as premium ceded divided by loss incurred. *Best's Rating* is the credit rating obtained from Best's Report. *Credit Downgrade* and *Credit Negative Watch* are dummy variables that equal to 1 if a firm got downgraded in previous year or is under negative credit watch respectively. *DPW/PHS* is the ratio of direct premium written over policyholder surplus (PHS). Δ *PHS* is % change of PHS over previous year. *Loss Volatility* is three-year moving average volatility of loss ratio. *Loss Development* measures the reserving error as one year loss development divided by total loss of most recent year. *Size* is log(asset). *ROE* is return on equity. *Leverage* is calculated as total liability over PHS. *Liquidity* is the sum of bond, stock and cash holding over total asset. *Dummy Stock & Public* are dummy variables if the firm is organized in the stock form or publicly traded. *, **, *** means that the test statistic is significant at 10%, 5% and 1% respectively.

	Model 1			Model 2			Model 3		
Reinsurance	Coefficient	Std Error	t Stat	Coefficient	Std Error	t Stat	Coefficient	Std Error	t Stat
Constant	0.5043	0.1230	4.1 ***	1.0695	0.0938	11.4 ***	0.8348	0.0890	9.38 ***
Derivative Dummy	-0.0364	0.0185	-1.97 **	-0.0383	0.0095	-4.04 ***	-0.0284	0.0084	-3.38 ***
% Premium in Earthquake Line				0.0112	0.1912	0.06	0.0698	0.1499	0.47
% Premium in Catastrophe States				0.0684	0.0093	7.32 ***	0.0457	0.0083	5.53 ***
% Premium in Property Liability Lines				0.1011	0.0112	9.01 ***	0.1041	0.0100	10.4 ***
Herfindahl - Line of Business				-0.1058	0.0131	-8.09 ***	-0.0515	0.0117	-4.39 ***
Herfindahl - Geographical				-0.1606	0.0098	-16.38 ***	-0.1227	0.0087	-14.07 ***
Herfindahl - Reinsurance				0.1780	0.0098	18.22 ***	0.1082	0.0088	12.25 ***
Reinsurance Sustainability				0.0186	0.0082	2.26 **	0.0086	0.0072	1.19
Reinsurance Price				0.0004	0.0001	2.73 ***	0.0002	0.0001	1.35
Credit Downgrade							0.0491	0.0110	4.46 ***
Credit Negative Watch							0.0407	0.0099	4.11 ***
Best's Rating							-0.0033	0.0006	-5.9 ***
DPW/PHS	0.0506	0.0017	29.05 ***				0.0414	0.0015	28.16 ***
$\triangle$ PHS	-0.0038	0.0117	-0.32				0.0017	0.0095	0.18
Loss Volatility	0.0012	0.0001	12.05 ***				0.0014	0.0001	13.06 ***
Loss Development	0.1252	0.0148	8.49 ***				0.0686	0.0154	4.45 ***
Size	-0.0053	0.0049	-1.07	-0.0220	0.0040	-5.53 ***	-0.0172	0.0037	-4.62 ***
Return on Equity	-0.0272	0.0176	-1.54	0.0043	0.0201	0.21	0.0020	0.0183	0.11
Leverage	-0.0410	0.0027	-15.09 ***	-0.0016	0.0029	-0.55	-0.0327	0.0028	-11.61 ***
Liquidity	-0.3101	0.0281	-11.05 ***	-0.5665	0.0262	-21.6 ***	-0.3536	0.0251	-14.11 ***
Dummy - Stock Firm	0.1230	0.0095	12.91 ***	0.0999	0.0080	12.44 ***	0.0866	0.0071	12.15 ***
Dummy - Public Firm	-0.0142	0.0106	-1.35	-0.0174	0.0111	-1.57	-0.0045	0.0098	-0.46
N	8666			7950			7330		
Adj. R^2	0.3525			0.2871			0.4134		

Table 3: **Reinsurance Hedging - with Derivative Market Value**

Shows the coefficients and test statistics of two stage simultaneous regression: Reinsurance equation. Dependent variable, *Reinsurance Usage*, is total reinsurance premium ceded divided by total premium written. Among the independent variables, the hedging alternative variable, *Derivative Market Value*, is the estimated market value of derivative hedging positions. *% Premium in Earthquake Line* is % of direct premium written (DPW) in earthquake line of business. *% Premium in Catastrophe States* is % of DPW in catastrophe-prone states. *% Premium in Property Liability Lines* is % of DPW in long-tail property-liability lines. *Herfindahl Line of Business, Geographical and Reinsurance* represent herfindahl index on line of business premium written, geographical premium written and reinsurance concentration respectively. *Reinsurance Sustainability* is % of premium ceded to reinsurers who provide reinsurance to the same company in all of previous three years. *Reinsurance Price* represents the price of reinsurance, calculated as premium ceded divided by loss incurred. *Best's Rating* is the credit rating obtained from Best's Report. *Credit Downgrade* and *Credit Negative Watch* are dummy variables that equal to 1 if a firm got downgraded in previous year or is under negative credit watch respectively. *DPW/PHS* is the ratio of direct premium written over policyholder surplus (PHS). Δ *PHS* is % change of PHS over previous year. *Loss Volatility* is three-year moving average volatility of loss ratio. *Loss Development* measures the reserving error as one year loss development divided by total loss of most recent year. *Size* is log(asset). *ROE* is return on equity. *Leverage* is calculated as total liability over PHS. *Liquidity* is the sum of bond, stock and cash holding over total asset. *Dummy Stock & Public* are dummy variables if the firm is organized in the stock form or publicly traded. *, **, *** means that the test statistic is significant at 10%, 5% and 1% respectively.

	Model 1			Model 2			Model 3		
Reinsurance	Coefficient	Std Error	t Stat	Coefficient	Std Error	t Stat	Coefficient	Std Error	t Stat
Constant	0.5630	0.0600	9.39 ***	1.1168	0.0712	15.68 ***	0.9001	0.0753	11.96 ***
Derivative - Market Value	-0.1430	0.0634	-2.26 **	-0.4016	0.0738	-5.44 ***	-0.1845	0.0676	-2.73 **
% Premium in Earthquake Line				0.1057	0.1480	0.71	0.1605	0.1364	1.18
% Premium in Catastrophe States				0.0878	0.0085	10.31 ***	0.0511	0.0078	6.57 ***
% Premium in Property Liability Lines				0.1086	0.0104	10.42 ***	0.1027	0.0095	10.80 ***
Herfindahl - Line of Business				-0.1107	0.0119	-9.27 ***	-0.0519	0.0118	-4.39 ***
Herfindahl - Geographical				-0.1663	0.0088	-19.01 ***	-0.1241	0.0078	-15.82 ***
Herfindahl - Reinsurance				0.1880	0.0088	21.35 ***	0.1073	0.0086	12.48 ***
Reinsurance Sustainability				0.0209	0.0075	2.78 **	0.0134	0.0067	2.00 *
Reinsurance Price				0.0005	0.0001	3.68 ***	0.0002	0.0001	2.27 **
Credit Downgrade							0.0461	0.0106	4.36 ***
Credit Negative Watch							0.0274	0.0095	2.89 ***
Best's Rating							-0.0035	0.0006	-6.27 ***
DPW/PHS	0.0570	0.0029	19.80 ***				0.0467	0.0027	17.09 ***
△ PHS	0.0073	0.0085	0.86				0.0047	0.0094	0.50
Loss Volatility	0.0014	0.0002	8.23 ***				0.0016	0.0002	8.67 ***
Loss Development	0.1257	0.0150	8.39 ***				0.0755	0.0158	4.78 ***
Size	-0.0088	0.0021	-4.12 ***	-0.0249	0.0027	-9.18 ***	-0.0214	0.0027	-7.83 ***
Return on Equity	-0.0134	0.0199	-0.67	-0.0199	0.0183	-1.09	0.0166	0.0168	0.99
Leverage	-0.0417	0.0035	-11.87 ***	-0.0013	0.0028	-0.45	-0.0347	0.0036	-9.58 ***
Liquidity	-0.2631	0.0263	-9.99 ***	-0.5898	0.0232	-25.39 ***	-0.3280	0.0257	-12.77 ***
Dummy - Stock Firm	0.1108	0.0059	18.64 ***	0.1205	0.0075	16.03 ***	0.0866	0.0068	12.66 ***
Dummy - Public Firm	-0.0129	0.0085	-1.51	-0.0330	0.0100	-3.31 ***	-0.0111	0.0091	-1.21
N	7380			7367			7330		
Adj. R^2	0.1645			0.2741			0.4135		

Table 4: **Reinsurance Hedging - with Derivative Notional Value**

Shows the coefficients and test statistics of two stage simultaneous regression: Reinsurance equation. Dependent variable, *Reinsurance Usage*, is total reinsurance premium ceded divided by total premium written. Among the independent variables, the hedging alternative variable, *Derivative Notional Value*, is the estimated notional value of derivative hedging positions. *% Premium in Earthquake Line* is % of direct premium written (DPW) in earthquake line of business. *% Premium in Catastrophe States* is % of DPW in catastrophe-prone states. *% Premium in Property Liability Lines* is % of DPW in long-tail property-liability lines. *Herfindahl Line of Business, Geographical and Reinsurance* represent herfindahl index on line of business premium written, geographical premium written and reinsurance concentration respectively. *Reinsurance Sustainability* is % of premium ceded to reinsurers who provide reinsurance to the same company in all of previous three years. *Reinsurance Price* represents the price of reinsurance, calculated as premium ceded divided by loss incurred. *Best's Rating* is the credit rating obtained from Best's Report. *Credit Downgrade* and *Credit Negative Watch* are dummy variables that equal to 1 if a firm got downgraded in previous year or is under negative credit watch respectively. *DPW/PHS* is the ratio of direct premium written over policyholder surplus (PHS). Δ *PHS* is % change of PHS over previous year. *Loss Volatility* is three-year moving average volatility of loss ratio. *Loss Development* measures the reserving error as one year loss development divided by total loss of most recent year. *Size* is log(asset). *ROE* is return on equity. *Leverage* is calculated as total liability over PHS. *Liquidity* is the sum of bond, stock and cash holding over total asset. *Dummy Stock & Public* are dummy variables if the firm is organized in the stock form or publicly traded. *, **, *** means that the test statistic is significant at 10%, 5% and 1% respectively.

	Model 1			Model 2			Model 3		
Reinsurance	Coefficient	Std Error	t Stat	Coefficient	Std Error	t Stat	Coefficient	Std Error	t Stat
Constant	0.5900	0.0683	8.64 ***	1.0915	0.0854	12.78 ***	0.9253	0.0877	10.55 ***
Derivative - Notional Amount	-0.0041	0.0031	-1.32	-0.0161	0.0036	-4.47 ***	-0.0056	0.0033	-1.70 *
% Premium in Earthquake Line				0.0915	0.1505	0.61	0.1742	0.1386	1.26
% Premium in Catastrophe States				0.0759	0.0084	9.05 ***	0.0461	0.0077	5.99 ***
% Premium in Property Liability Lines				0.1086	0.0106	10.29 ***	0.1012	0.0096	10.49 ***
Herfindahl - Line of Business				-0.1051	0.0118	-8.89 ***	-0.0488	0.0117	-4.16 ***
Herfindahl - Geographical				-0.1623	0.0091	-17.87 ***	-0.1235	0.0081	-15.25 ***
Herfindahl - Reinsurance				0.1881	0.0088	21.34 ***	0.1076	0.0086	12.52 ***
Reinsurance Sustainability				0.0209	0.0075	2.77 **	0.0138	0.0067	2.05 **
Reinsurance Price				0.0004	0.0001	3.65 ***	0.0002	0.0001	2.24 **
Credit Downgrade							0.0444	0.0106	4.20 ***
Credit Negative Watch							0.0272	0.0095	2.87 ***
Best's Rating							-0.0035	0.0006	-6.23 ***
DPW/PHS	0.0567	0.0029	19.81 ***				0.0465	0.0027	17.08 ***
△ PHS	0.0080	0.0085	0.94				0.0055	0.0094	0.59
Loss Volatility	0.0014	0.0002	8.25 ***				0.0016	0.0002	8.75 ***
Loss Development	0.1262	0.0150	8.43 ***				0.0767	0.0158	4.86 ***
Size	-0.0095	0.0025	-3.81 ***	-0.0231	0.0033	-7.07 ***	-0.0220	0.0033	-6.76 ***
Return on Equity	-0.0135	0.0198	-0.68	-0.0227	0.0182	-1.25	0.0151	0.0167	0.90
Leverage	-0.0413	0.0035	-11.84 ***	-0.0017	0.0028	-0.61	-0.0345	0.0036	-9.58 ***
Liquidity	-0.2641	0.0264	-10.00 ***	-0.5955	0.0234	-25.50 ***	-0.3283	0.0258	-12.71 ***
Dummy - Stock Firm	0.1082	0.0060	18.17 ***	0.1193	0.0078	15.37 ***	0.0840	0.0071	11.87 ***
Dummy - Public Firm	-0.0130	0.0090	-1.44	-0.0374	0.0105	-3.57 ***	-0.0112	0.0096	-1.17
N	7380			7367			7330		
Adj. R^2	0.1689			0.2736			0.4131		

Table 5: **Derivative Hedging - Probit Analysis of Derivative Dummy**

Shows the coefficients and test statistics of two stage simultaneous probit regression: Derivative equation. Dependent variable, *Derivative Dummy*, equals to one if the insurer reports to use derivatives for hedging purpose. Among the independent variables, the hedging alternative variable, *Reinsurance Usage*, is the estimated level of reinsurance premium ceded as a fraction of total premium written. *% Premium in Earthquake Line* is % of direct premium written (DPW) in earthquake line of business. *% Premium in Catastrophe States* is % of DPW in catastrophe-prone states. *% Premium in Property Liability Lines* is % of DPW in long-tail property-liability lines. *Herfindahl Line of Business and Geographical* represent herfindahl index on line of business premium written and geographical premium written respectively. *Best's Rating* is the credit rating obtained from Best's Report. *Credit Downgrade* and *Credit Negative Watch* are dummy variables that equal to 1 if a firm got downgraded in previous year or is under negative credit watch respectively. *Turnover* is the sum of investment proceeds and investment acquired divided by total assets. *Duration Gap* is the difference in duration of assets and liability. *% Bond & Risky Bond* are the % of firms total asset invested in bond and risky bond respectively. Same definition applies for *% Stock, Mortgage & Real Estate*. *% Foreign Asset* is % of total asset invested in countries other than U.S. and Canada. *Size* is log(asset). *ROE* is return on equity. *Leverage* is calculated as total liability over PHS. *Liquidity* is the sum of bond, stock and cash holding over total asset. *Dummy Stock & Public* are dummy variables if the firm is organized in the stock form or publicly traded. *, **, *** means that the test statistic is significant at 10%, 5% and 1% respectively.

	Model 1			Model 2			Model 3		
Reinsurance	Coefficient	Std Error	t Stat	Coefficient	Std Error	t Stat	Coefficient	Std Error	t Stat
Constant	-6.2135	0.7300	-8.51 ***	-1.2427	0.2759	-4.5 ***	-6.3006	1.0391	-6.06 ***
Reinsurance Usage	-0.9773	0.4031	-2.42 **	-0.8680	0.2937	-2.95 ***	-1.3053	0.4892	-2.67 ***
% Premium in Earthquake Line							-5.7716	3.9824	-1.45
% Premium in Catastrophe States							-0.1418	0.1211	-1.17
% Premium in Property Liability Lines							0.3546	0.1382	2.57 **
Herfindahl - Line of Business							-0.2186	0.1753	-1.25
Herfindahl - Geographical							-0.0106	0.1349	-0.08
Turnover				0.0341	0.0140	2.43 **	0.0289	0.0149	1.93 *
Duration Gap				0.0848	0.0123	6.88 ***	0.0785	0.0129	6.1 ***
% Bond				-2.4779	0.3867	-6.41 ***	-1.3167	0.4970	-2.65 ***
% Risky Bond				1.4328	0.3286	4.36 ***	0.5341	0.3499	1.53
% Stock				0.5430	0.3329	1.63	0.6618	0.4480	1.48
% Mortgage				7.7971	2.3392	3.33 ***	7.4012	2.5453	2.91 ***
% Real Estate				-4.6487	2.1930	-2.12 **	-4.1613	2.3102	-1.8 *
% Foreign Asset				2.3838	1.1549	2.06 **	-0.9086	1.3135	-0.69
Credit Downgrade	0.3643	0.1034	3.52 ***				0.3992	0.1161	3.44 ***
Credit Negative Watch	0.2921	0.0981	2.98 ***				0.3477	0.1101	3.16 ***
Best's Rating	0.0108	0.0060	1.81 *				0.0134	0.0069	1.94 *
Size	0.2537	0.0216	11.74 ***				0.2602	0.0321	8.11 ***
Return on Equity	-0.2490	0.1747	-1.43				-0.0626	0.2163	-0.29
Leverage	-0.0611	0.0301	-2.03 **				0.0240	0.0342	0.7
Liquidity	-0.9799	0.3582	-2.74 ***				-0.7667	0.5254	-1.46
Dummy - Stock Firm	0.4986	0.0937	5.32 ***				0.2902	0.1011	2.87 ***
Dummy - Public Firm	-0.3018	0.1098	-2.75 ***				-0.1079	0.1277	-0.84
N	8666			7350			7330		
Pseudo R^2	0.1540			0.1223			0.2557		

Table 6: **Derivative Hedging - Cragg's Tobit Analysis of Market Value of Derivative Hedging**

Shows the coefficients and test statistics of two stage simultaneous probit regression: Derivative equation. Dependent variable, *Derivative Market Value*, is the market value of derivative hedging position of a given insurer. Among the independent variables, the hedging alternative variable, *Reinsurance Usage*, is the estimated level of reinsurance premium ceded as a fraction of total premium written. *% Premium in Earthquake Line* is % of direct premium written (DPW) in earthquake line of business. *% Premium in Catastrophe States* is % of DPW in catastrophe-prone states. *% Premium in Property Liability Lines* is % of DPW in long-tail property-liability lines. *Herfindahl Line of Business and Geographical* represent herfindahl index on line of business premium written and geographical premium written respectively. *Best's Rating* is the credit rating obtained from Best's Report. *Credit Downgrade* and *Credit Negative Watch* are dummy variables that equal to 1 if a firm got downgraded in previous year or is under negative credit watch respectively. *Turnover* is the sum of investment proceeds and investment acquired divided by total assets. *Duration Gap* is the difference in duration of assets and liability. *% Bond & Risky Bond* are the % of firms total asset invested in bond and risky bond respectively. Same definition applies for *% Stock, Mortgage & Real Estate*. *% Foreign Asset* is % of total asset invested in countries other than U.S. and Canada. *Size* is log(asset). *ROE* is return on equity. *Leverage* is calculated as total liability over PHS. *Liquidity* is the sum of bond, stock and cash holding over total asset. *Dummy Stock & Public* are dummy variables if the firm is organized in the stock form or publicly traded. *, **, *** means that the test statistic is significant at 10%, 5% and 1% respectively.

	Model 1			Model 2			Model 3		
Reinsurance	Coefficient	Std Error	t Stat	Coefficient	Std Error	t Stat	Coefficient	Std Error	t Stat
Constant	-0.5829	0.0621	-9.39 ***	-0.0485	0.0154	-3.16 ***	0.1027	0.1717	0.60
Reinsurance Usage	-0.0990	0.0234	-4.24 ***	-0.1158	0.0179	-6.46 ***	-0.0541	0.0513	-1.06
% Premium in Earthquake Line							0.6405	0.5526	1.16
% Premium in Catastrophe States							0.0893	0.0142	6.29 ***
% Premium in Property Liability Lines							-0.0448	0.0187	-2.40 **
Herfindahl - Line of Business							-0.0738	0.0141	-5.22 ***
Herfindahl - Geographical							0.0324	0.0130	2.49 **
Turnover				0.0078	0.0016	4.91 ***	-0.0118	0.0047	-2.53 **
Duration Gap				0.0060	0.0007	8.07 ***	0.0039	0.0022	1.80 *
% Bond				-0.2898	0.0312	-9.28 ***	-0.0192	0.0823	-0.23
% Risky Bond				0.1800	0.0270	6.66 ***	0.0715	0.0551	1.30
% Stock				0.0160	0.0181	0.88	0.3022	0.0652	4.64 ***
% Mortgage				0.6486	0.3019	2.15 **	1.9618	0.6020	3.26 ***
% Real Estate				-0.8923	0.1621	-5.50 ***	-0.4857	0.2598	-1.87 *
% Foreign Asset				-0.0331	0.0789	-0.42	-0.0434	0.1572	-0.28
Credit Downgrade	0.0051	0.0099	0.52				-0.0011	0.0117	-0.09
Credit Negative Watch	-0.0144	0.0115	-1.25				-0.0177	0.0145	-1.23
Best's Rating	0.0008	0.0006	1.31				0.0006	0.0014	0.43
Size	0.0232	0.0021	11.14 ***				0.0146	0.0065	2.27 **
Return on Equity	0.0131	0.0182	0.72				0.0911	0.0267	3.41 ***
Leverage	0.0004	0.0027	0.14				0.0267	0.0053	5.01 ***
Liquidity	-0.0610	0.0279	-2.18 **				0.0381	0.0745	0.51
Dummy - Stock Firm	0.0507	0.0079	6.42 ***				0.0314	0.0108	2.90 **
Dummy - Public Firm	-0.0460	0.0114	-4.05 ***				-0.0301	0.0142	-2.12 *
N	8952			8931			8911		
Log Likelihood	-748			-791			-667		

Table 7: **Derivative Hedging - Cragg's Tobit Analysis of Notional Amount of Derivative Hedging**

Shows the coefficients and test statistics of two stage simultaneous probit regression: Derivative equation. Dependent variable, *Derivative Notional Value*, is the notional value of derivative hedging position of a given insurer. Among the independent variables, the hedging alternative variable, *Reinsurance Usage*, is the estimated level of reinsurance premium ceded as a fraction of total premium written. *% Premium in Earthquake Line* is % of direct premium written (DPW) in earthquake line of business. *% Premium in Catastrophe States* is % of DPW in catastrophe-prone states. *% Premium in Property Liability Lines* is % of DPW in long-tail property-liability lines. *Herfindahl Line of Business and Geographical* represent herfindahl index on line of business premium written and geographical premium written respectively. *Best's Rating* is the credit rating obtained from Best's Report. *Credit Downgrade* and *Credit Negative Watch* are dummy variables that equal to 1 if a firm got downgraded in previous year or is under negative credit watch respectively. *Turnover* is the sum of investment proceeds and investment acquired divided by total assets. *Duration Gap* is the difference in duration of assets and liability. *% Bond & Risky Bond* are the % of firms total asset invested in bond and risky bond respectively. Same definition applies for *% Stock, Mortgage & Real Estate*. *% Foreign Asset* is % of total asset invested in countries other than U.S. and Canada. *Size* is log(asset). *ROE* is return on equity. *Leverage* is calculated as total liability over PHS. *Liquidity* is the sum of bond, stock and cash holding over total asset. *Dummy Stock & Public* are dummy variables if the firm is organized in the stock form or publicly traded.*, **, *** means that the test statistic is significant at 10%, 5% and 1% respectively.

	Model 1			Model 2			Model 3		
Reinsurance	Coefficient	Std Error	t Stat	Coefficient	Std Error	t Stat	Coefficient	Std Error	t Stat
Constant	-5.1602	0.5263	-9.80 ***	-0.3085	0.1370	-2.25 **	-5.6480	0.7187	-7.86 ***
Reinsurance Usage	-1.0042	0.2216	-4.53 ***	-1.3631	0.1716	-7.94 ***	-1.0645	0.3078	-3.46 ***
% Premium in Earthquake Line							-6.3744	3.6535	-1.74 *
% Premium in Catastrophe States							0.0171	0.0859	0.20
% Premium in Property Liability Lines							0.3556	0.0909	3.91 ***
Herfindahl - Line of Business							-0.1961	0.1085	-1.81 *
Herfindahl - Geographical							0.2437	0.0878	2.77 ***
Turnover				0.0802	0.0179	4.48 ***	0.0789	0.0182	4.35 ***
Duration Gap				0.0529	0.0077	6.86 ***	0.0370	0.0097	3.81 ***
% Bond				-3.1144	0.3300	-9.44 ***	-1.1308	0.4378	-2.58 ***
% Risky Bond				1.8773	0.3032	6.19 ***	0.4266	0.3599	1.19
% Stock				0.0410	0.1723	0.24	0.5399	0.3815	1.42
% Mortgage				5.8173	1.8569	3.13 ***	8.5098	2.4711	3.44 ***
% Real Estate				-9.1702	1.5926	-5.76 ***	-9.0651	1.8796	-4.82 ***
% Foreign Asset				0.9056	0.6993	1.30	-2.2351	1.1179	-2.00 **
Credit Downgrade	0.0477	0.0929	0.51				0.0789	0.0916	0.86
Credit Negative Watch	-0.1152	0.0994	-1.16				-0.1157	0.1163	-1.00
Best's Rating	0.0102	0.0056	1.83 *				0.0196	0.0078	2.50 **
Size	0.2302	0.0182	12.63 ***				0.2410	0.0246	9.80 ***
Return on Equity	0.1866	0.1489	1.25				0.5059	0.1823	2.77 ***
Leverage	0.0141	0.0265	0.53				0.0583	0.0323	1.80 *
Liquidity	-1.0130	0.2272	-4.46 ***				-0.8202	0.3786	-2.17 **
Dummy - Stock Firm	0.2747	0.0627	4.38 ***				0.2156	0.0649	3.32 ***
Dummy - Public Firm	-0.5034	0.1150	-4.38 ***				-0.3984	0.1239	-3.22 ***
N	8952			8931			8911		
Log Likelihood	-1265			-1343			-1125		

Table 8: **Sorting of Derivative Hedging by Size**

Shows the number of insurance firms that fall into each quartile. Firms are sorted by their asset value. In addition, firms are sorted based on market value (normalized by asset value) and notional amount (normalized by asset value) of hedging positions.

	User	Market Value					Notional Amount				
Asset	Dummy	Q1	Q2	Q3	Q4	Total	Q1	Q2	Q3	Q4	Total
Q1	22	2	0	1	11	14	3	6	0	5	14
Q2	12	2	0	4	3	9	4	3	1	1	9
Q3	47	3	3	9	3	18	3	2	5	9	19
Q4	155	31	36	23	22	112	31	29	34	26	120
Total	236	38	39	37	39	153	41	40	40	41	162

A Appendix: Endogeneity Check

The endogeneity test results of two-step GMM estimation. This table shows the validity of the set of instruments, both included and excluded. Dependent variable, *Reinsurance Usage*, is total reinsurance premium ceded divided by total premium written. The independent variables follow the definition given in Table 1.

Reinsurance	Coefficient	Std Error	
Constant	1.0610	0.4028	***
Derivative - Dummy	-0.0464	0.5848	
% Premium in Earthquake Line	0.1530	0.2711	
% Premium in Catastrophe States	-0.0072	0.0432	
% Premium in Property Liability Lines	0.1016	0.0508	**
Herfindahl - Line of Business	-0.1044	0.0549	*
Herfindahl - Geographical	-0.1534	0.0434	***
Herfindahl - Reinsurance	0.1628	0.0466	***
Reinsurance Sustainability	0.0520	0.0181	***
Reinsurance Price	0.0238	0.0358	
Credit Downgrade	0.0291	0.0564	
Credit Negative Watch	0.0733	0.0486	
Best's Rating	-0.0064	0.0027	**
DPW/PHS	0.0090	0.0145	
△ PHS	-0.0255	0.0392	
Loss Volatility	0.0020	0.0004	***
Loss Development	0.1844	0.0694	***
Size	-0.0340	0.0213	
Return on Equity	-0.0167	0.0671	
Leverage	-0.0060	0.0160	
Liquidity	-0.2762	0.1160	**
Dummy - Stock Firm	0.0539	0.0379	
Dummy - Public Firm	0.0381	0.0425	
N	7330		
Hansen J statistic	2.932		
Chi-sq(6) P-value	0.8140		
Difference-in-Sargan statistic	0.027		
Chi-sq(1) P-value	0.8701		

Instrumented: Derivative - Dummy and Reinsurance Price. Instruments tested: % of Premium in Earthquake Line. Included instruments: % Premium in Earthquake Line, % Premium in Catastrophe States, % Premium in Property Liability Lines, Herfindahl - Line of Business, Herfindahl - Geographical, Herfindahl - Reinsurance, Reinsurance Sustainability, Credit Downgrade, Credit Negative Watch, Best's Rating, DPW/PHS, △ PHS, Loss Volatility, Loss Development, Size, Return on Equity, Leverage, Liquidity, Dummy - Stock Firm, Dummy - Public Firm. Excluded instruments: Turnover, Duration Gap, % Bond, % Risky Bond, % Stock, % Mortgage, % Real Estate, % Foreign Asset. Test results for other instruments are similar to this one, which are available from the authors upon request.