Diversification, Underwriting Risk, and Reinsurance

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Abstract

We investigate the extent to which insurers in the U.S. Property-Liability insurance industry utilize reinsurance to reduce underwriting risk, and we compare this effect to the effect of reinsurance on diversification. An important contribution of the research is the construction of a new measure of diversification that accounts for both risk and correlation. We find that among insurers that purchase reinsurance, insurers with greater diversification in their underwriting business prior to the purchase of reinsurance purchase less reinsurance than do less-diversified insurers. This result conflicts with prior findings. We also find that while some insurers hold less risk following the purchase of reinsurance, this is not always the case. We find that almost 40% of reinsurance purchases result in an increase in underwriting risk for the ceding insurer. Additionally, many insurers also reduce their level of diversification by purchasing reinsurance. This may signal that insurers substitute reinsurance and diversification.

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Introduction

Diversification and reinsurance are two mechanisms through which insurers can reduce underwriting risk. Diversification occurs when an insurer's underwriting portfolio contains variation in lines of business and/or comprises different geographic regions in a way that allows pooling to reduce the total underwriting risk held by the insurer. Reinsurance is the transfer of risk from one insurance company to another in exchange for a fee. The conventional wisdom is that the purchase of reinsurance reduces underwriting risk for an insurer by allowing the insurer to shift or transfer risk to a reinsurer, and many prior studies associate this transfer of risk with a reduction in the variability of losses, earnings, or cash flows for the ceding insurer.[1] A missing component to the argument that reinsurance reduces underwriting risk is that there is an interaction between reinsurance and diversification. When a primary insurer transfers risk to a reinsurer, the insurer alters its business mix, which affects its level of diversification, which, in turn, affects its underwriting risk. As a result, the net effect of reinsurance on underwriting risk is unknown. In this work, we isolate one mechanism through which reinsurance affects underwriting risk with the objective of understanding the interplay between diversification and reinsurance.

We begin by studying the reinsurance behavior of U.S. Property-Liability insurers. We identify firm characteristics and business activities that are associated with observable reinsurance behaviors. Among the characteristics we consider are the level of diversification and the total risk of each insurer's underwriting portfolio *prior to* the purchase of reinsurance. We then measure diversification and risk *after* the purchase of reinsurance in order to determine how reinsurance impacts these features. This allows us to identify the extent to which insurers use reinsurance to

[1] For example: Mayers and Smith (1982, 1990), Skipper (1998), Garven and Lamm-Tennant (2003), Harrington and Niehaus (2004), Cole and McCullough (2006), Skipper and Kwon (2007), Vaughan and Vaughan (2008).

reduce risk through a re-balancing of the insurers' underwriting portfolios. The result of this re-balancing, we will demonstrate, is similar to that achieved through business mix diversification.

We find that insurers with more underwriting risk prior to the purchase of reinsurance purchase more reinsurance than those with less underwriting risk and are less likely to increase risk through the purchase of reinsurance. At the same time, insurers with more extensive underwriting diversification purchase less reinsurance. That is, insurers appear to substitute reinsurance for diversification. This is in contrast to prior findings. Cole and McCullough (2006) identify the possibility that diversified insurers purchase less reinsurance, but instead find evidence that the more focused is an insurer, the less reinsurance the insurer purchases.

Additionally, we find that many insurers increase underwriting risk when they purchase reinsurance. When insurers do hold less net underwriting risk following the purchase of reinsurance, this outcome often is accompanied by a decrease in diversification. That is, insurers may reduce the average risk in their portfolio by buying reinsurance, but at the same time, these insurers decrease underwriting diversification through the reinsurance purchase, which *increases* risk. While this results in a net decrease of underwriting risk, the direct impact on average risk is contrary to the indirect impact on net risk through the change in diversification.

We contribute to the literature in several ways. First, we introduce a methodology to measure insurer underwriting risk. We then extend this to include insurer diversification by providing a measure of diversification that considers the risk and correlation, as well as both the geographic and line of business distribution, of insurers' underwriting activities. These measures allow this and future work to focus on the portfolio aspect of insurer diversification. This portfolio approach to diversification, in turn, highlights the nuances of the interrelatedness of risk and diversification, a relationship that is studied in many research streams. We further contribute to the reinsurance

literature by providing evidence that contrasts prior findings that insurers opt for strategic focus in their underwriting activities.

The remainder of the paper is organized as follows. In Section 2, we describe the measurement of risk and diversification in insurance underwriting. We describe our data and relevant data considerations in Section 3. In Section 4, we carry out the measurements described in Section 2 using our data. We describe our analyses and discuss the results in Section 5. Section 6 concludes.

Section 2 - Measuring Risk and Diversification in Insurance.

Underwriting Portfolio Risk

The variance (or "risk") of a portfolio, $\sigma_p{}^2$, can be determined as

$$\sigma_p{}^2 = \sum_{i=1}^{n} w_i{}^2 \, \sigma_i{}^2 + 2 \sum_{i=1}^{n} \sum_{j<i}^{n} w_i w_j \sigma_i \sigma_j \rho_{ij} \qquad (1)$$

where w_j is the proportion of the portfolio held in asset or liability j, σ_j is the standard deviation of asset or liability j, and ρ_{ij} is the correlation between assets or liabilities i and j.[2] In words, the determination of portfolio risk requires the standard deviation of each underlying component in the portfolio, the weight assigned to each of those components, and the correlations among them. Initially, we define an insurer's underwriting portfolio as the collection of all lines of business, though only the lines in which the insurer operates will have non-zero weights.

We seek a general measure of risk for each line of business that fits two criteria. First, the measure should generalize the experience of all insurers writing in the line. We can achieve this

[2] Here we will be focused on an insurer's underwriting risk; hence, will be considering each insurer's underwriting liabilities, which we will measure by loss ratios.

using cross sectional data. Second, the measure should account for time-varying influences such as market trends, economic shocks, and natural catastrophes. Therefore, we must expand the cross sectional data approach to consider multiple time periods in the determination of the correlations across lines of business. Data limitations faced in non-financial industries often prohibit a clean assessment of risk and correlation. In the insurance world, however, we have available detailed financial data to calculate such values. We describe the implementation of these measures and the construction of underwriting portfolio risk in Section 4.

Diversification

Diversification occurs with the pooling of assets or liabilities. In insurance underwriting, insurers achieve diversification by pooling the liabilities arising from the policies written across lines of business and geographic areas. While we can gain some sense of the variety of this pool by counting the number of lines of business or geographies in which each insurer conducts business, potentially even considering the relative proportions of their business activities, these features alone do not fully capture the core elements of diversification. Also needed are measures of risk and correlation.

The simplest measure of insurer diversification used in the literature is a count of states or lines of business (or both) in which an insurer operates (Lamm-Tennant and Starks, 1993; Liebenberg and Sommer, 2008). While such a measure offers a sense of breadth, it considers neither the extent of business written in each state or line nor the level of similarity (or difference) across states and lines. Proportional measures, such as Herfindahl-Hirschman Index (HHI) based measures, improve upon the count measures by recognizing the relative influence of each state or line.[3]

[3] Proportional measures other than HHI are employed by Berger et al. (2000), Choi and Weiss (2005), Chen et al. (2008), Liebenberg and Sommer (2008), Berry-Stolzle, Hoyt, and Wende (2013), and Morris et al. (2017). Herfindahl measures of diversification are dominant in the literature: McCullough and Hoyt (2002), Chen et al. (2008), Liebenberg and Sommer (2008), Berry-Stolzle et al. (2012), Che and Liebenberg (2017), and Morris et al. (2017) use

Perhaps more importantly, HHI is a way to capture the concentration of an insurer's activities and to do so through a single number, which allows it to be applied easily as a control variable in economic models. Additionally, HHI has an intuitive interpretation that allows a comparison across individual insurers. An insurer with a line level HHI of *n* is as equivalently concentrated as is an insurer writing in 1/*n* lines in equal proportions. The shortcoming of this measure is that it does not include the correlation of underwriting losses across lines of business. This becomes evident upon recognizing that the use of HHI will yield the same outcome, whether the lines in which the insurer operates are similar or dissimilar, and whether the lines are volatile or stable.

Our measure of an insurer's level of underwriting diversification compares the insurer's underwriting portfolio risk to the portfolio risk that would be present if all lines of business were perfectly positively correlated. Perfect positive correlation implies the absence of diversification; hence, we measure underwriting portfolio risk in the absence of diversification and compare this counterfactual result to the true risk in the portfolio in order to determine the level of diversification taking place within the portfolio. We refer to this comparison as the "Diversification Ratio (DR)," and it is a measure of how much risk reduction has been achieved through the firm's choice of component parts (lines and state-lines in our analyses).[4]

Said another way, we know that if all risks in a portfolio are perfectly positively correlated, no diversification is occurring. Therefore, we impose perfect positive correlation between every pair of lines in each insurer's portfolio. The ratio of this counterfactual risk measurement outcome to the actual risk in the portfolio yields DR. A key feature of diversification is that it reduces risk

HHI to measure geographic and/or LOB concentration. Elango et al. (2008) uses the Shannon Entropy Measure, which is similar to HHI in construction and interpretation. These measures are also found in the reinsurance literature. For example: Cole and McCullough (2006) uses Herfindahl measures for geographic and line of business diversification, Mayers and Smith (1990) uses a Herfindahl for line of business diversification and the negative of the number of states licensed as a measure of geographical diversification.

[4] DR has been used in the literature, although not often. See Choueifaty and Coignard (2008).

relative to this counterfactual. If the risk in the two scenarios (the actual and the counterfactual) are equivalent, then no diversification is occurring in the portfolio.

We can construct DR for each insurer ($\propto$) in each year (t) as

$$DR_{\propto t} = \frac{\sigma_{counterfactual,t}}{\sigma_{actual,t}}, \tag{2}$$

with

$$\sigma_{actual,t} = \left(\sum_{i=1}^{n} {w_{it}}^2 {\sigma_{it}}^2 + 2 \sum_{i=1}^{n} \sum_{j<i}^{n} w_{it} w_{jt} \sigma_{it} \sigma_{jt} \rho_{ijt} \right)^{1/2}, \tag{3}$$

and

$$\sigma_{counterfactual,t} = \left(\sum_{i=1}^{n} {w_{it}}^2 {\sigma_{it}}^2 + 2 \sum_{i=1}^{n} \sum_{j<i}^{n} w_{it} w_{jt} \sigma_{it} \sigma_{jt} \cdot 1 \right)^{1/2} = \sum_{i} w_{it} \sigma_{it}, \tag{4}$$

where w_{it} is the insurer's proportion of premiums written in line i in year t, σ_{it} is the standard deviation of loss ratios in line i from time t_{-5} to t_{-1}, and ρ_{ijt} is the correlation between line i and line j from time t_{-5} to t_{-1}. Note that in the counterfactual case, all correlations are equal to one.

Section 3 - Data

We use data from the National Association of Insurance Commissioners (NAIC) database from 1991 to 2014. The initial analyses rely on premium and loss data at the line of business (LOB) level, which we collect from the Exhibit of Premiums and Losses of the annual NAIC statement, and the line of business level reinsurance data, which we collect from the Underwriting and Expense Exhibit. We consider stock and mutual insurers, and our dataset includes all group and

unaffiliated individual single insurers. We consider all U.S. states and protectorates across 23 lines of business.[5]

The use of these data for our analyses presents several challenges resulting from our desire to include geographic considerations in the measurements of diversification and risk. In addition to the construction of the portfolios as described in Section 2, we perform a parallel analyses in which we construct insurers' underwriting portfolios at a more granular level. Specifically, we introduce into each insurer's portfolio the geographic (rather than solely line of business) distribution of its underwriting activities. To accomplish this, we construct the portfolios as before, but we do so on the state-line level.[6] Constructing the portfolios from these data allows us to extend our measurement of risk and diversification to include insurers' geographical underwriting decisions.

Analysis at the LOB level is straightforward, because we have both direct premiums written and total reinsurance purchased on the LOB level for all insurers. This enables us to measure risk within each LOB and the correlation among them, as well as to determine exactly each insurer's portfolio weights before and after reinsurance. We describe this process in detail in Section 4. Unfortunately, reinsurance data at the state-line level is not reported by insurers. Therefore, while we can make all required measurements at the state-line level in the absence of reinsurance, the construction of an insurer's state-line portfolio after the reinsurance purchase requires us to estimate the weights. We describe this estimation in Section 4.

[5] The set of 23 lines is: Accident and Health, Aircraft, Boiler and Machinery, Burglary and Theft, Commercial Auto, Commercial Multiple Peril, Credit, Earthquake, Farmowners, Fidelity, Financial Guaranty, Fire and Allied lines, Homeowners, Inland Marine, Medical Professional Liability, Mortgage Guaranty, Ocean Marine, Other Liability, Personal Auto, Products Liability, Surety, Warranty, and Workers' Compensation.

[6] Examples of state-lines include: Homeowners in California, Workers' Compensation in Wisconsin, and Workers' Compensation in Maryland.

Despite the additional challenge of reinsurance estimation, state-line level analyses provide tremendous benefits over the LOB level analyses. First, we can consider how geographically concentrated are insurers. Furthermore, we are able to determine and include the risk within each state within each line and the correlations among these state-lines, resulting in a measure of geographic diversification. Importantly, we need not combine separate measures of underwriting risk and diversification based on geographic and line of business activities. Instead, we construct insurer portfolios in a way that considers these components inherently. In this way, we distinguish among insurers writing business in multiple states from those writing in only a few states. Additionally, we are able to consider *which* lines of business insurers are writing in *which* states.

To see the value in this, consider an insurer writing an equal amount of business in two states, say Florida (FL) and Texas (TX), and an equal amount in two lines, say Homeowners (HO) and Inland Marine (Inland). This insurer could be writing both lines in each of the states, yielding 4 state-lines: HO in FL, HO in TX, Inland in FL, and Inland in TX. However, this insurer could also be writing only HO in FL and only Inland in TX. Importantly, this scenario generates multiple potential state-line portfolios, each having a different level of risk and diversification even if we hold LOB and state concentrations constant. Considering LOB and geographic diversification separately does not allow differentiation of the state-line portfolios.

Another benefit to working on the state-line level is that we are able to incorporate variation in an insurer's level of diversification within a line of business in a single measure. For a single line insurer, the prior analysis would reveal that there is no diversification taking place in the insurer's portfolio. Yet, if this insurer is operating in multiple states within that line, the use of a state-line based portfolio allows us to both identify that the insurer is, in fact, diversified, as well as allowing us to identify changes in this level of diversification over time, even if the insurer is a

single line insurer throughout our time frame. Simply stated, state-line considerations allow us to recognize that an insurer writing only Homeowners insurance in Wisconsin and Florida is diversified geographically, though it only writes in one line of business. For these reasons, the state-line level analysis provides a measure that more fully captures the risk and diversification in an underwriting portfolio.

Section 4 - Metric Construction

In this section, we describe how we carry out the measurement of underwriting risk and diversification (described in Section 2) using our data (described in Section 3).

We calculate LOB underwriting risk as follows. For every line of business and every year, we determine the line level loss ratio for each insurer writing business in that line in that year. We use the ratio of direct losses incurred in the line to the direct premiums written in the line.[7] We then determine the risk in each line as the standard deviation of these loss ratios across all insurers writing business in the line.[8] We do this for each 5-year time window.[9]

To measure correlations across lines of business, we define a line/line pair for insurer $\propto$ in year t as

$$(LR_i, LR_j)_{\propto t}\ , \qquad (5)$$

where LR_i is the loss ratio (direct losses incurred to direct premiums written) in line of business *i*, and LR_j is the ratio in line of business *j*. We construct all such loss ratio pairings appearing in our

[7] Because we are interested in the overall market experience, we use direct premiums at this stage of the analysis.
[8] The use of standard deviation of loss ratios as a measure of risk is used in Lamm-Tennant and Starks (1993), Chidambaran et al. (1997), Harrington and Niehaus (1999), Panjer and Fia (2001), Cummins, et al. (2008), and others. Here we apply this measure of risk on a line level analysis. As described in Section 3, we also apply this at the state-line level. In that detailed application, our loss ratio pairs are defined for all pairs of state-lines.
[9] The results are robust to the use of 3-year, 5-year, and 7-year time windows.

data. The correlation in year *t* between line *i* and line *j* is determined as the correlation of all observed line/line pairs for the two lines occurring between years *t-5* and *t-1*, inclusive.[10]

We use as the weight for each line in an insurer's portfolio, the insurer's proportion of direct premiums written in that particular line. That is, the initial weights do not consider reinsurance usage. We describe the inclusion of reinsurance later in this section. Using the portfolio weights, the standard deviation of each line, and the correlations between each pair of lines, we measure each insurer's underwriting portfolio risk prior to the purchase of reinsurance.

We also construct these measures at the state-line level. Direct premiums written and direct losses incurred are available at the state-line level. This allows us to construct the state-line level portfolios in the absence of reinsurance in the same way we constructed LOB level portfolios.

The use of reinsurance may result in an increased or decreased level of risk and an increased or decreased level of diversification for the ceding insurer. To see how this is possible, consider as an example an insurer writing in three lines of business, and assume that the outcome in each of these lines is independent of the others. Suppose the insurer writes 25% of its total direct premiums written in Line 1, 25% in Line 2, and 50% in Line 3. If the risk in Line 3 is greater than the risk in the other lines, the purchase of reinsurance in Line 3 will reduce the portfolio risk and increase diversification.[11] However, if the risk is larger in the other lines than in Line 3, the purchase of reinsurance in Line 3 will result in increased risk and increased diversification. As a second example, suppose an insurer writes 50% of its business in each of two independent lines. If the

[10] As with the determination of risk within a line, we also carry out the measurements of correlation for 3-year and 7-year time windows.

[11] This is true until the proportion of net premiums written in Line 3 is equivalent to the proportion written in the other two lines. Reinsurance purchase in Line 3 beyond this point would result in reduced diversification. We can say this is true in this example only because we have assumed independence. With non-zero correlation between the lines, the effect of reinsurance on portfolio risk and diversification is unclear.

insurer fully reinsures one line, the diversification in the portfolio will decrease, but the effect of reinsurance on the portfolio risk depends on the relative risk in each of the lines.

The key take away from the above examples is that the result of the purchase of reinsurance on an insurer's risk and diversification is unclear, with the result depending on the specific portfolio and the characteristics of the components. Furthermore, the two measures (risk and diversification) move somewhat independently, which may be counterintuitive. That is, the purchase of reinsurance may or may not affect diversification and risk in the same way. An insurer may decrease its level of diversification with the purchase of reinsurance, but this does not imply that the post-reinsurance portfolio will have more risk than the pre-reinsurance portfolio. The purpose of our analyses is to observe the level of underwriting risk and diversification that insurers actually achieve with the purchase of reinsurance.

The introduction of reinsurance at the line of business level is straightforward. The line of business level risk and correlations previously determined remain valid, as they capture the underlying risk within the lines and relationships among the lines irrespective of the distribution of those risks within any portfolio. While the purchase of reinsurance changes an insurer's portfolio, it does not change the characteristics of or relationships among the underlying portfolio components. The inclusion of reinsurance, which is reported at the line of business level, requires only a reconstruction of the portfolio weights within each insurer's portfolio. To carry out the measurement in the presence of reinsurance, we determine the weights based on net premiums written, rather than direct premiums written. Importantly, this reweighting changes the risk in the portfolio under both actual and counterfactual scenarios.

While direct premium data are available on the state-line level, data regarding reinsurance usage are available only at the line level (not the state-line level). Therefore, we must estimate the amount of reinsurance purchased for each state-line.

To carry out this estimation and determine the proper weights for the portfolio components in the presence of reinsurance at the state-line level, we proceed as follows. For each insurer-year-line observation in our data, we construct a multiplier,

$$M_{\alpha tl} = \frac{Net\ Premiums\ Written_{\alpha tl}}{Direct\ Premiums\ Written_{\alpha tl}}. \quad (6)$$

We then estimate the following model:

$$M_{\alpha tl} = \beta_0 + \boldsymbol{\beta} \cdot \boldsymbol{DPW_{\alpha tsl}} + \tau_t + \omega_\alpha + \gamma_l + \varepsilon_{\alpha tl}, \quad (7)$$

where $\boldsymbol{DPW_{\alpha tsl}}$ is a vector of state (*s*) level direct premiums written (proportionally) by insurer α in year *t* in line of business *l*, τ_t is a year fixed-effect, ω_α is a firm fixed-effect, $\gamma_l$is a line of business fixed-effect, and $\varepsilon_{\alpha tl}$ is an error term. Net premiums written for insurer α in year *t* in state *s* in line of business *l* is then determined as

$$NPW_{\alpha tsl} = DPW_{\alpha tsl} \times \left(\widehat{\beta_0} + \hat{\beta} \cdot DPW_{\alpha slt} + \widehat{\tau_t} + \widehat{\omega_\alpha} + \widehat{\gamma_l}\right). \quad (8)$$

We use the model results to estimate net premiums written (used as weights) on the state-line level. As in the LOB analysis, we determine DR and portfolio risk (now at the state-line level) in the presence of reinsurance.

Section 5 - Results

Our interest lies in understanding the impact of reinsurance on risk and diversification. As a first step, we want to understand how an insurer's risk position and level of diversification prior to the purchase of reinsurance are related to the extent of the insurer's reinsurance purchase. We therefore consider only firms that purchase some amount of reinsurance.

We begin by determining the risk within and correlations among the lines of business as described in Section 4 for each year beginning in 1996.[12] We construct all loss ratio pairings as described in Equation 5 appearing in our data.[13]

Given 23 lines of business and 58 geographies, there exists the potential for 1334 loss ratio observations per insurer per year. Requiring each state-line/state-line (SLSL) pair to be unique and excluding the pairings in which $SL_1 = SL_2$ ("diagonal" observations), each insurer has the potential to produce 889,111 SLSL pairs per year.[14] That is, if a single insurer conducts business in all 23 lines of business and in all 58 geographies in a single year, we observe 889,111 unique SLSL pairs for that insurer. Carrying out this process on our data yields 126,890,931 unique SLSL pairs. We use these observed pairs to determine the correlation values necessary to measure diversification, while the 867,624 insurer-year-state-line loss ratio observations allow the determination of the state-line level risk as described in Section 4.

We use portfolio weights based on direct premiums written and apply Equation 1 to determine the risk in each insurer-year portfolio. We then use Equation 2 to measure the level of

[12] Because our data begin in 1991, a 5-year time window for the correlation and risk measures is required to assess the underwriting risk and diversification levels for insurers. Longer time windows reduce the usable years of data. Though we have conducted these analyses, as described in Section 4, the results of the analyses conducted with a 5-year window are those which we present in this paper.

[13] We construct this set of pairings at both the line of business and state-line level. Here, we describe the details of the state-line level construction.

[14] We have 23 LOBs and 58 "states," which includes the 50 U.S. states, Washington D.C., and 7 U.S. territories and protectorates. 23 * 58 = 1334. Then, we have 889,111 = ((1334 * 1334) – 1334)/2 potential unique SLSL pairs.

diversification within each insurer-year portfolio. We do this first at the line of business level and then again at the state-line level. A summary of these results is provided in Table 1.

From Table 1 we see that the mean DR for all insurers when determined at the state-line level is 1.609. This diversification measure can be interpreted in two ways. An insurer with a DR of 1.609 is as equivalently diversified as is an insurer writing business in $1.609^2 = 2.589$ independent, equal variance state-lines in equal proportions. This measure allows for a comparison across insurers. Another interpretation is that an insurer with a DR of 1.609 would face 1.609 times the risk it currently faces if there were no diversification occurring in the portfolio. This interpretation requires no external comparison and follows directly from the construction of the measure in Equation 2.

We employ the measures of pre-reinsurance diversification and underwriting portfolio risk to investigate the relationship between these characteristics and the extent of the reinsurance purchase by insurers. To do this, we measure the reinsurance purchase for each insurer in each year as the ratio of reinsurance ceded to direct premiums written, the Reinsurance Ratio.[15] We then estimate

$$Reins_{\alpha t} = \beta_0 + \beta_1 UPR_{\alpha t} + \beta_2 DR_{\alpha t} + \boldsymbol{B} LOB\_props_{\alpha t} + \tau_t + \varepsilon_{\alpha t}, \qquad (9)$$

where, for insurer α in year *t*, $Reins_{\alpha t}$ is the amount of reinsurance purchased (as a proportion of direct premiums written), $UPR_{\alpha t}$ is the underwriting portfolio risk prior to the purchase of reinsurance, $DR_{\alpha t}$ is the Diversification Ratio prior to the purchase of reinsurance, $LOB\_props_{\alpha t}$ is a vector containing the proportions of business written in all lines of business,[16], τ_t is a year fixed-effect, and $\varepsilon_{\alpha t}$ is an error term. The results of this estimation are provided in Table 3. Also

[15] The Reinsurance Ratio, defined as the ratio of reinsurance premiums ceded to premiums written, is a common measure of the reinsurance purchase. See for example: Mayers and Smith (1990), Berger et. al. (1992), and Cole and McCullough (2006).

[16] The descriptive statistics for the proportions of insurer direct premiums written across lines of business are provided in Table 2.

provided in the table are estimations of models in which portfolio risk and DR are considered separately.

Model 1 in Table 3 does not include a firm fixed effect. This allows us to exploit the cross sectional variation in the data. Interpretation of the results at the state-line level reveals that a firm with the average diversification level purchases about 19% more reinsurance than does a firm with a diversification level one standard deviation above the mean. This result is statistically significant and changes only minimally with the inclusion of portfolio risk. In Model 4, we include a firm fixed effect. This significantly reduces the variability in the data, because it is rare that an insurer experiences a large shift in its diversification level. We find that the comparison described above results in an increase in the reinsurance purchase of 2.5% with the inclusion of the firm fixed-effect.

In order to more clearly illustrate and visualize the relationship between an insurer's pre-reinsurance level of diversification and the extent of the reinsurance purchase, we approach the model described in Equation 9 in an alternative fashion. Figure 1 is a binned scatter plot of the Reinsurance Ratio on the y-axis and the Diversification Ratio (at the state-line level) on the x-axis. This plot corresponds to the regression in Column 1 of Table 3 and uses the same sample restrictions and variable definitions. To construct the binned scatter plots, we first residualize the y-axis variable with respect to a control vector. This vector controls for the line of business proportions and a year fixed effect as in the model described in Equation 9. We then residualize the x-axis variable with respect to the control vector. We divide the residualized Diversification Ratios into ten equal-sized groups (deciles) and plot the means of the Reinsurance Ratio residuals within each bin against the mean value of the Diversification Ratio residuals within each bin. We add back the unconditional mean of the y variable in the estimation sample to facilitate

interpretation of the scale. Each dot shows the average Reinsurance Ratio for a given level of Diversification Ratio, holding the controls constant. Note that this binned scatter plot provides a non-parametric representation of the conditional expectation function but does not show the underlying variance in the individual-level data. We also plot the best linear fit line, constructed from an OLS regression of the y-residuals on the x-residuals. The slope of the fit line matches the coefficient on the multivariate regression in Column 1 of Table 3. We also carry out this process to illustrate the relationship between the reinsurance purchase and underwriting portfolio risk prior to the purchase of reinsurance. This chart is included in Figure 2.

After the purchase of reinsurance

Having established a relationship between the amount of reinsurance purchased by an insurer and that insurer's levels of diversification and risk *prior to* the purchase of reinsurance, we next consider the effect of the reinsurance purchase on these insurer portfolio characteristics. In order to do this, we construct a new portfolio for each insurer wherein the weights are based on the insurer's net premiums written, as described in Section 4. We consider as valid insurer-year observations all portfolios with non-negative net premiums in all components of their portfolio.

The purchase of reinsurance cannot create diversification for an insurer that has no diversification prior to the reinsurance purchase. More specifically, an insurer with a DR = 1 has all of its direct premium weight in a single portfolio component. When some of the premiums in this component are ceded to a reinsurer, the weight in the single component of the insurer's portfolio remains 1. Therefore, the insurer with a DR of 1 before reinsurance will have a DR of 1 after the purchase of reinsurance, regardless of the proportion of premiums ceded. A parallel argument can be made that the ceding insurer's portfolio risk remains unchanged following the

purchase of reinsurance when the insurer's portfolio has exactly one non-zero weight. In order to study the impact of reinsurance on diversification and portfolio risk, we limit our observations to insurers that have some level of diversification (a DR > 1) prior to the purchase of reinsurance.

As described in Section 3, the measurement of portfolio risk and diversification can be carried out on the LOB level or the state-line level. A corollary to the benefits of conducting analyses at the state-line level is that single line insurers writing in multiple states remain in our analyses while they are removed as non-diversified insurers in the LOB level analyses. The descriptive statistics for DR and underwriting portfolio risk at the line of business and state-line levels are provided in Table 4 as measured both prior to and following the purchase of reinsurance.

In Section 4, we described how the effect of reinsurance on underwriting risk and diversification is unclear. Before examining the extent to which these factors are altered following the purchase of reinsurance, we first investigate how likely is it that reinsurance *increases* the risk and diversification in insurers' portfolios.[17] Table 5 provides a breakdown of the directional impact that the reinsurance purchase has on diversification and risk in insurer portfolios.

From Table 5, we observe that when DR and risk are determined on the state-line level, more than 50% of reinsurance purchases result in a reduction of diversification for the insurer. Of this subset of firms experiencing reduced diversification, 62.5% also see an increase in the underwriting risk. Importantly, 90% of insurers that increased diversification through the purchase of reinsurance also experienced a reduction in portfolio risk.[18] Turning our focus to the effect of reinsurance on risk, we find that of the 38% of the reinsurance purchases that resulted in increased portfolio risk, almost 90% were also accompanied by a decrease in diversification.

[17] Importantly, because our analysis is done at the firm-year level, and we are observing the risk in the portfolio prior to and following the purchase of reinsurance, we are observing a causal relationship.

[18] Though this may seem intuitive, a reduction in risk does not necessarily accompany an increase in diversification, as shown in the first example of Section 4.

We conduct the same analysis at the line of business level. At this level, we have data for the reinsurance purchase. We see largely similar results, removing the concern that our estimation of the reinsurance purchase at the state-line level significantly influences our results. The difference in the magnitude of the outcomes is likely driven by the fact that the geographic diversification of an insurer's activities is not considered at the line of business level.

Next, we consider the probability that the risk in the insurer's portfolio increases with the purchase of reinsurance using a more robust approach. To do this, we estimate the probit model

$$UPR\_UP_{\alpha t} = \beta_0 + \beta_1 UPR_{\alpha t} + \beta_2 DR_{\alpha t} + \beta_3 Size_{\alpha t} + \beta_4 ROA_{\alpha t} + \beta_2 CapitalAsset_{\alpha t} + \boldsymbol{B} LOB\_props_{\alpha t} + \gamma_\alpha + \tau_t + \varepsilon_{\alpha t}, \quad (10)$$

where, for insurer α in year *t*, $UPR\_UP_{\alpha t}$ is an indicator variable with a value of 1 if the risk in the insurer's portfolio is larger following the purchase of reinsurance and 0 otherwise; $UPR_{\alpha t}$, $DR_{\alpha t}$, and $LOB\_props_{\alpha t}$ are as described previously; $Size_{\alpha t}$ is measured as log of total assets; $ROA_{\alpha t}$ is the return on assets; $CapitalAsset_{\alpha t}$ is the capital-to-asset ratio (policyholder surplus divided by total assets); γ_α, τ_t, and $\varepsilon_{\alpha t}$ are firm fixed-effects, year fixed-effects, and an error term, respectively. We carry out this estimation at the state-line and line of business levels. These results are presented in Table 6, and plots of the margins are in Figure 3.

We observe that as the level of pre-reinsurance diversification increases, the probability that the purchase of reinsurance results in an increase in portfolio risk decreases. This is in line with the results presented in Table 5.

Section 6 - Conclusion

In this work, we create and apply a measure of diversification in the insurance industry that accounts for correlations across the insurers' underlying business. We do this both at the line of

business level and at the state-line level. The state-line measure allows us to consider geographic as well as business product variation, which the results suggest are meaningful.

With this measure, we are able to observe the effect of reinsurance on both risk and diversification. While many reasons exist to purchase reinsurance and to diversify across product lines and geographies, one prominent reason for both is to manage risk. With an effective measure in hand, we are able to isolate and observe this impact.

Our results suggest that the relationship between reinsurance usage and the risk and diversification within an insurer's underwriting portfolio is rich and complex, deserving of extensive future analyses to understand the strategic decisions made by insurance executives. Among insurers that purchase reinsurance, riskier insurers buy more reinsurance and well-diversified insurers buy less. The effect, however, is not always a reduction in risk. We find that about 40% of all observed reinsurance purchase decisions result in an increase in underwriting risk for the ceding insurer. Furthermore, we observe that the purchase of reinsurance inherently alters an insurer's portfolio mix, and often reduces an insurer's level of diversification. In this way, we believe that reinsurance and diversification may act as substitutes.

There are considerations to made when interpreting our results. First, our application of reinsurance when determining the weights in the underwriting portfolios assumes proportional reinsurance. Because the type of reinsurance purchased is not reported, we cannot distinguish between proportional and excess of loss reinsurance. This does not affect our initial findings regarding the pre-reinsurance measurement outcomes and the amount of reinsurance purchased, but it would have some impact on our post-reinsurance measurement of both risk and diversification. In the future, we plan to perform further analyses using insurers that write only small proportions of their business in lines that may suggest extensive use of non-proportional

reinsurance. By isolating lines in which excess of loss reinsurance is more common, we can restrict our data in a way that makes insurers' usage of proportional reinsurance more likely across our observations.

Additionally, as described earlier, we estimate the reinsurance purchased on the state-line level in order to determine the state-line portfolio weights in parts of our analysis. The measurement of the portfolio risk is more sensitive to estimation errors than is the measurement of diversification, but the potential for mis-estimation remains in both measures. The outcomes from measurements made at the line of business level do not face this problem and are in alignment with the outcomes resulting from measurement at the state-line level. Given the robustness of our results, we are not concerned about these estimation issues.

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Table 1: Descriptive statistics

This table contains the descriptive statistics for insurer portfolio risk (Underwriting portfolio risk), diversification level (Diversification Ratio (DR)), size measured as log of total assets (Size), and the number of lines of business (LOBs), states, and state-lines. Column 1 shows the results at the state-line level, and Column 2 is determined at the line of business level. The statistics are provided for all insurers (top), diversified insurers (middle), and non-diversified insurers (bottom). Here, we define a diversified insurer to be an insurer with a DR strictly greater than 1. That is, an insurer with some level of diversification.

	State-line level measures				Line of business level measures			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Variable	All insurers (N = 15495)				All insurers (N = 15495)			
Underwriting portfolio risk	1.254	2.076	0.007	76.809	2.824	7.907	0.126	75.338
Diversification Ratio (DR)	1.609	0.669	1.000	5.072	1.264	0.289	1.000	2.462
Size	18.030	2.304	12.217	26.328	18.030	2.304	12.217	26.328
Number of LOBs	4.351	3.865	1.000	22.000	4.351	3.865	1.000	22.000
Number of states	10.036	15.534	1.000	57.000	10.036	15.534	1.000	57.000
Number of state-lines	40.026	101.656	1.000	873.000	40.026	101.656	1.000	873.000
	Diversified insurers (N = 12225)				Diversified insurers (N = 10519)			
Underwriting portfolio risk	1.071	1.739	0.020	76.809	1.865	4.128	0.135	75.266
Diversification Ratio (DR)	1.772	0.665	~1.000	5.072	1.389	0.273	~1.000	2.462
Size	18.469	2.252	12.217	26.328	18.546	2.304	12.217	26.328
Number of LOBs	5.247	3.890	1.000	22.000	5.936	3.766	2.000	22.000
Number of states	12.453	16.678	1.000	57.000	12.781	17.324	1.000	57.000
Number of state-lines	50.464	112.169	2.000	873.000	56.941	119.576	2.000	873.000
	Non-diversified insurers (N = 3270)				Non-diversified insurers (N = 4976)			
Underwriting portfolio risk	1.936	2.919	0.007	28.241	4.852	12.354	0.126	75.338
Diversification Ratio (DR)	1.000	0.000	1.000	1.000	1.000	0.000	1.000	1.000
Size	16.388	1.667	12.721	23.713	16.939	1.884	12.721	23.713
Number of LOBs	1.001	0.030	1.000	2.000	1.000	0.000	1.000	1.000
Number of states	1.000	0.000	1.000	1.000	4.232	8.208	1.000	53.000
Number of state-lines	1.000	0.000	1.000	1.000	4.268	8.398	1.000	89.000

Table 2: Percentage of direct premiums written by line of business

This table contains the breakdown of direct premiums written by line of business. All insurer-year portfolios were used to determine these values. These data provide insight into the construction of insurer underwriting portfolios. In most of the analyses in this work, we control for each insurer's proportional business mix.

Line of business	Mean	SD	Min	Max
Accident and Health	1.27%	9.00%	0.00	1.00
Aircraft	0.09%	1.34%	0.00	0.57
Allied Lines	9.94%	17.82%	0.00	1.00
Boiler and Machinery	0.07%	0.60%	0.00	0.15
Burglary and Theft	0.08%	1.06%	0.00	0.52
Commercial Auto	5.73%	14.80%	0.00	1.00
Commercial Multiple Peril	8.89%	17.12%	0.00	1.00
Credit	0.43%	5.40%	0.00	1.00
Earthquake	0.32%	2.78%	0.00	0.82
Farmowners	4.10%	10.06%	0.00	0.94
Fidelity	0.11%	2.05%	0.00	1.00
Financial Guaranty	0.59%	7.54%	0.00	1.00
Homeowners	19.60%	24.82%	0.00	1.00
Inland Marine	1.86%	7.89%	0.00	1.00
Medical Professional Liability	5.80%	22.48%	0.00	1.00
Mortgage Guaranty	0.82%	8.82%	0.00	1.00
Ocean Marine	0.42%	4.55%	0.00	1.00
Other Liability	6.90%	17.20%	0.00	1.00
Personal Auto	19.64%	30.25%	0.00	1.00
Products Liability	0.42%	3.96%	0.00	1.00
Surety	3.33%	16.54%	0.00	1.00
Warranty	0.33%	5.11%	0.00	1.00
Workers' Compensation	9.26%	24.45%	0.00	1.00

Table 3: Estimation of Reinsurance Proportion Models – Equation 9.

These models consider the state-line (SL) level measurements of diversification (DR) and the underwriting portfolio risk (UPR) prior to the purchase of reinsurance. The dependent variable in all models is the Reinsurance Ratio. This is defined as the amount of premiums ceded to reinsurance divided by the total direct premiums written by the insurer. All models have year fixed effects as well as controls for the proportion of business written in each line in the year of measurement. Models 4 - 6 also include firm fixed effects. Standard errors are reported in parentheses below the coefficient. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
SL Level DR	-0.0794 ***		-0.0790 ***	-0.0112 **		-0.0095 *
	(0.004)		(0.004)	(0.004)		(0.004)
SL Level UPR		0.0074 ***	0.0006		0.0017 *	0.0013
		(0.001)	(0.001)		(0.001)	(0.001)
Line of Business Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm Fixed Effects	No	No	No	Yes	Yes	Yes
Number of Observations	9,493	9,493	9,493	9,493	9,493	9,493
R^2	0.1540	0.1140	0.1540	0.0220	0.0220	0.0220
Adjusted R^2	0.150	0.110	0.150	-0.130	-0.130	-0.130

Summary statistics for reinsurance proportion models

Variable	Mean	Std Dev.	Min	Max
State-line level DR	1.678	0.592	~ 1.000	4.725
State-line level UPR	1.117	1.903	0.061	76.808
Reins. proportion	0.246	0.209	~ 0.000	0.999

Table 4: Descriptive statistics for DR and underwriting portfolio risk

In this table, we provide descriptive statistics for Diversification Ratio (DR) and underwriting portfolio risk (UPR). This is done first at the state-line level and then at the line of business level. In each of these cases, the measures are made prior to the reinsurance purchase (based on direct premiums written) and after the reinsurance purchase (based on net premiums written). At the state-line level, net premiums written are estimated as described in Section 4. On average, state-line level DR is larger than line of business level DR, because this measure considers geographical diversification as well as business mix diversification.

	Num Obs	Mean	SD	Min	Max
State-line level					
DR based on **direct** premiums written	9493	1.678	0.592	1.000	4.725
UPR based on **direct** premiums written	9493	1.118	1.903	0.062	76.809
DR based on **net** premiums written	9493	1.678	0.594	1.000	4.825
UPR based on **net** premiums written	9493	1.111	1.894	0.065	73.607
Line of business level					
DR based on **direct** premiums written	9244	1.380	0.266	1.000	2.444
UPR based on **direct** premiums written	9244	1.862	4.238	0.135	75.266
DR based on **net** premiums written	9244	1.387	0.267	1.000	2.461
UPR based on **net** premiums written	9244	1.904	4.476	0.137	75.338

Table 5: Comparison of diversification and insurer portfolio risk pre- and post-reinsurance

In this table, we summarize the effect of the reinsurance purchase on insurer diversification and underwriting risk. Diversification is measured via the Diversification Ratio (DR). The measures of DR and underwriting portfolio risk (UPR) are carried out prior to the purchase of reinsurance, based on direct premiums written, and then after the reinsurance purchase, based on net premiums written. The left panel contains measures carried out at the state-line level (which includes geographic diversification), while the right panel contains measures at the line of business level. Reinsurance on the line of business level is known exactly, and reinsurance on the state-line level is estimated as described in Section 4.

	State-line level (N = 9493)			**Line of business level (N = 9244)**		
	Number of Observations	Proportion in Category	Conditional Proportion	Number of Observations	Proportion in Category	Conditional Proportion
DR smaller after reinsurance:	5020	52.88%	Of these…	4487	48.54%	Of these…
… and UPR smaller	1881		37.47%	1235		27.52%
… and UPR larger	3139		62.53%	3252		72.48%
DR larger after reinsurance:	4464	47.02%	Of these…	4756	51.45%	Of these…
… and UPR smaller	4024		90.14%	3547		74.58%
… and UPR larger	440		9.86%	1209		25.42%
DR unchanged by reinsurance:	9	0.09%		1		
UPR smaller after reinsurance:	5905	62.20%	Of these…	4782	51.73%	Of these…
… and DR smaller	1881		31.85%	1235		25.83%
… and DR larger	4024		68.15%	3547		74.17%
UPR larger after reinsurance:	3579	37.70%	Of these…	4461	48.26%	Of these…
… and DR smaller	3139		87.71%	3252		72.90%
… and DR larger	440		12.29%	1209		27.10%
UPR unchanged by reinsurance:	9	0.09%		1		

Table 6: Probit model estimation for increased risk following the purchase of reinsurance

This table presents the results of the probit regression described in Equation 10. The dependent variable is equal to one if the risk in the post-reinsurance portfolio is larger than the risk in the pre-reinsurance portfolio, and it is zero otherwise. *Diversification Ratio* is the level of diversification in the insurer-year portfolio prior to the purchase of insurance. *Underwriting Risk* is the risk in the insurer-year portfolio prior to the purchase of reinsurance. *Size* is the natural logarithm of total assets. *ROA* is net income divided by total assets. *Capital-to-Asset Ratio* is policyholder surplus divided by total assets. Column (1) and Column (2) are at the state-line level, with Column (2) adding firm fixed-effects. Column (3) and Column (4) are at the line of business level, with Column (4) adding firm fixed-effects. The following are omitted from the table to conserve space: the line of business control variables (the proportion of business written in each of the lines of insurance), and the year and firm fixed effects. The reported coefficients are average marginal effects. Robust z-statistics (clustered standard errors by firm) are in parentheses. ***, **, and * indicate two-tailed statistical significance at 0.01, 0.05, and 0.10 levels.

Variable	(1)	(2)	(3)	(4)
Diversification Ratio	-0.1048 ***	-0.1472 ***	-0.0054	-0.0453
	(-5.66)	(-4.34)	(-0.14)	(-0.81)
Underwriting Risk	0.0047	-0.0039	-0.0022	-0.0002
	(1.04)	(-0.77)	(-1.05)	(-0.04)
Size	0.0209 ***	-0.0070	0.0013	0.0693 ***
	(3.64)	(-0.25)	(0.25)	(2.88)
ROA	-0.1916	-0.0866	0.0313	-0.2785 *
	(-1.55)	(-0.55)	(0.23)	(-1.84)
Capital-to-Asset Ratio	0.0574	0.0298	-0.0460	0.1897 *
	(1.02)	(0.27)	(-0.74)	(1.68)
Line of Business Controls	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Firm Fixed Effects	No	Yes	No	Yes
Number of Observations	9,374	7,063	9,160	8,107
Number of Firms	1,217	1,217	1,057	1,057
Pseduo R^2	0.0603	0.2171	0.0445	0.2019
Log Likelihood	-5832.541	-3751.245	-6061.892	-4484.255

Figure 1: Pre-reinsurance diversification and the extent of the reinsurance purchase

This figure provides a visualization of the conditional expectation of the reinsurance purchase by an insurer for a given level of pre-reinsurance diversification. This result considers a year fixed effect as well as controls for the proportions of direct premiums written in each line of business. The details behind the construction of this figure are described in Section 5. We see that insurers with a higher level of pre-reinsurance diversification purchase less reinsurance than do less-diversified insurers. This figure illustrates the results of Model 1 in Table 3. Each dot shows the average Reinsurance Ratio for a given Diversification Ratio, and the slope of the line in the figure is equivalent to the coefficient on *SL Level DR* in Model 1 in Table 3.

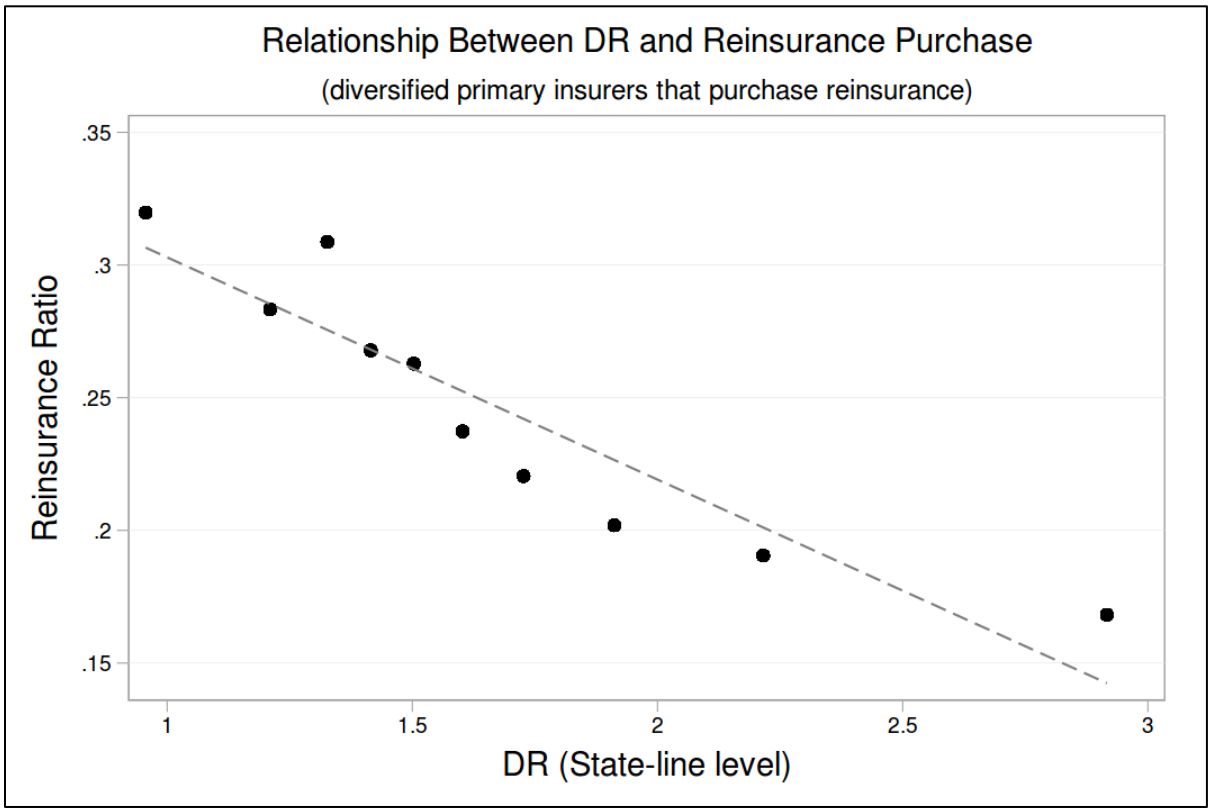

Figure 2: Pre-reinsurance portfolio risk and the extent of the reinsurance purchase

This figure provides a visualization of the conditional expectation of the reinsurance purchase by an insurer for a given level of pre-reinsurance portfolio risk. This result considers a year fixed effect as well as controls for the proportions of direct premiums written in each line of business. The details behind the construction of this figure are described in Section 5. We see that insurers with a higher level of pre-reinsurance underwriting risk purchase more reinsurance than do insurers with lower initial underwriting risk. This figure illustrates the results of Model 2 in Table 3. Each dot shows the average Reinsurance Ratio for a given level of portfolio risk, and the slope of the line in the figure is equivalent to the coefficient on *SL Level UPR* in Model 2 in Table 3.

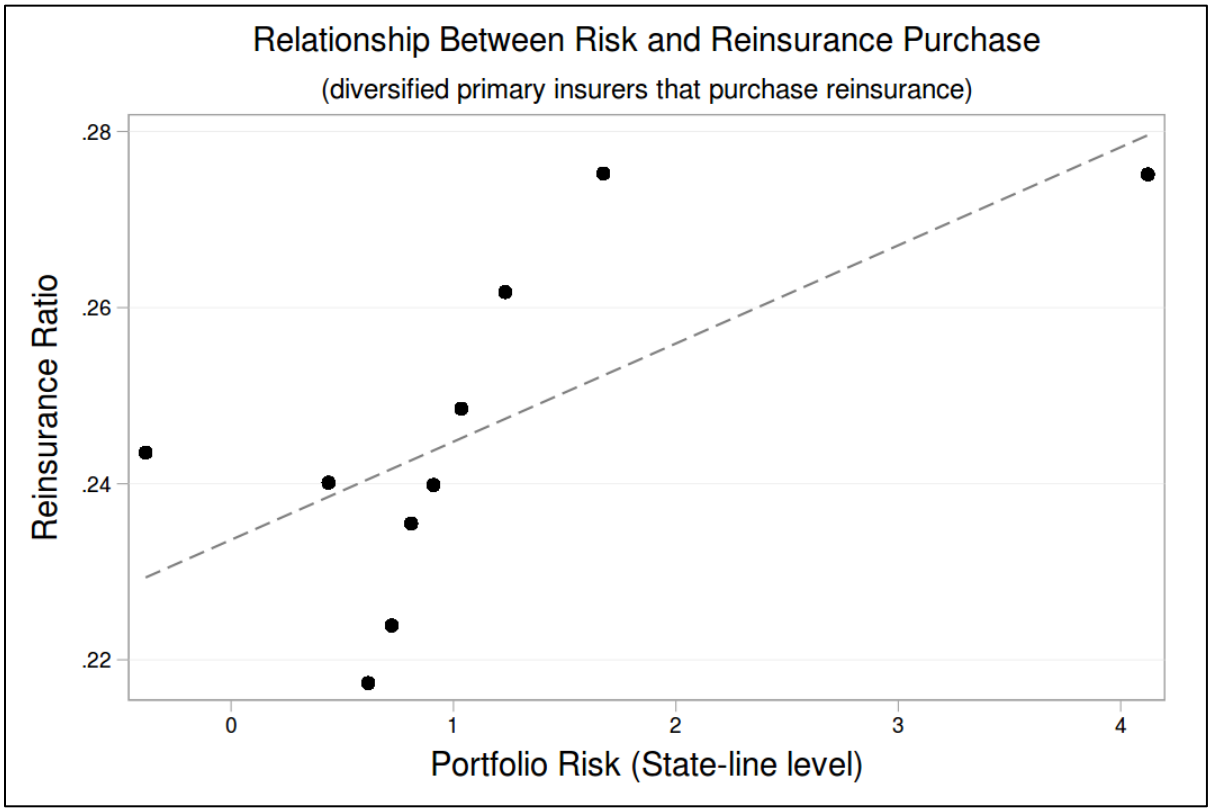

Figure 3: Marginal effects for the probability of increasing risk with the purchase of reinsurance

The marginal effects plots for the probit model described in Table 6 Model 2 (top panel) and Model 4 (bottom panel). The state-line level provides a clear and significant relationship between an insurers' pre-reinsurance diversification level and the probability of increased risk following the purchase of reinsurance. The lack of a significant relationship at the LOB level is likely a result of (1) the reduced range of diversification when measured at this level, and (2) a reduced variability in the diversification measure in the sample relative to its mean. The coefficient of variation in DR at the state-line level is almost twice as large as the LOB level. Though the state-line level analysis requires an estimation of the reinsurance purchase, Table 5 suggests that this estimation is not the source of the differences we see between these figures.