The Structure of the Global Reinsurance Market:

An Analysis of Efficiency, Scale, and Scope

Christian Biener, Martin Eling, Ruo Jia[1]

Abstract

We conduct a multidimensional DEA frontier efficiency analysis to study economies of scale, economies of scope, and cost efficiency in an industry where global risk diversification is the core of the business model. Reinsurers with total assets less than USD 2.9 billion exhibit scale economies, while those with assets greater than USD 15.5 billion do not. Large reinsurers are characterized by high cost efficiency. Small reinsurers exhibit superior efficiency when they are specialized. This research is original in terms of empirically explaining the structure of the global reinsurance market, in which large reinsurers dominate, but both diversified and specialized reinsurers can be successful.

Keywords: DEA, Efficiency, Service Operations, Market Structure, Economies of Scale and Scope, Diversification Strategies

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[1] Christian Biener (christian.biener@unisg.ch), Martin Eling (martin.eling@unisg.ch) and Ruo Jia (ruo.jia@unisg.ch) are affiliated with the Institute of Insurance Economics, University of St. Gallen, Rosenbergstrasse 22, 9000 St. Gallen, Switzerland. We are grateful to Gene Lai, Jan Hendrik Wirfs, Judith C. Schneider, Philipp Schaper, Tyler Leverty, Wei Zheng, and the anonymous reviewer of the 2015 Annual Conference of the Swiss Society for Financial Market Research (18th SGF conference) for their helpful inputs and comments to the paper.

1. INTRODUCTION

Reinsurers function as shock absorbers and risk bearers of last resort for the insurance industry and the global economy. They also provide real services to their clients, including underwriting, pricing, claim management, and consultancy, enabling them to protect individuals and institutions against risks such as natural catastrophes, terrorism, and longevity. Moreover, reinsurers, with large and long-term investment portfolios, are a reliable source of alternative capital to primary insurers and to the global economy.

The reinsurance industry has undergone significant change in the 21st century, preceded by a number of large-scale catastrophes, the 2008 financial crises, new competition from alternative risk transfer schemes, and new sources of capital, especially from hedge funds and pension funds (Butt, 2007; Cummins & Weiss, 2009). All of these factors have resulted in consolidation (Cole & McCullough, 2006; Cummins & Weiss, 2000) and structural change in the global reinsurance market.

Economies of scale and scope, as sources of diversification, are particularly relevant to the structure of the reinsurance market. The advantages offered by scale economies motivate market consolidation because large firms tend to be more scale efficient than small firms. Scope economies come into play when more diversified firms exhibit cost efficiency (or other performance) advantages relative to specialized firms (Clark, 1988; Elango, Ma, & Pope, 2008; Panzar & Willig, 1977, 1981). Borch (1960, 1962) takes a different perspective and argues that the global reinsurance market is structured around optimal risk allocation. He concludes that, in equilibrium, all reinsurers hold a proportional share of the "market portfolio" that pools all risks in the market. Borch's equilibrium implies complete diversification of risks with the market portfolio. The theories involving economies of scale and scope, as well as Borch's equilibrium, focus on two key features of the reinsurance business—size (scale) and diversification[2] (scope)—and thus provide a basis for analyzing their empirical validity.[3]

This paper makes four contributions. (1) We estimate reinsurer cost efficiency and total factor productivity using data envelopment analysis (DEA) with multiple inputs and outputs (Cook, Tone, & Zhu, 2014; Cummins, Weiss, & Zi, 1999). (2) We analyze economies of scale and scope for the global reinsurance market based on DEA frontier efficiency benchmarks (Cummins, Weiss, Xie, & Zi,

[2] This paper focuses on product diversification, an aspect not to date studied in the context of the global reinsurance market. Regarding geographic or international diversification in the reinsurance market, see, e.g., Cole, Lee, and McCullough (2007) and Outreville (2012a).

[3] Reinsurance is a persuasive context to analyze market structure, not only because of the variety of recent corporate strategic changes (Klarner & Raisch, 2013), but also because the industry-specific risk allocation problem (Borch, 1960, 1962). Other industry-specific elements, such as its intangible and regulated nature, make reinsurance a particular interesting context to analyze market structure. The regulated nature of reinsurance market may serve as entry barrier and limit the options for diversification.

2010; Cummins & Xie, 2013), thus explaining the real-world structure of the global reinsurance market. (3) We derive an optimal size range for reinsurers by uncovering thresholds at which scale economies are exhausted (Katrishen & Scordis, 1998). (4) We test the efficient structure (ES) hypothesis (Choi & Weiss, 2005) in the global reinsurance market, under which efficient firms are expected to be more competitive because they charge lower prices without sacrificing profitability. To our knowledge, none of these analyses have been conducted previously.[4]

Our empirical results suggest that reinsurance industry productivity improved significantly from 2002 to 2012, due to both technical progress and best-practice adoption by initially less efficient reinsurers. The consideration of scale efficiency yields an optimal size range for reinsurers of between USD 2.9 and 15.5 billion in total assets (inflation adjusted at 2012). Scale diseconomies of the largest reinsurers are offset by their strong positions in X-efficiency (i.e., cost efficiency excluding scale efficiency); hence, the largest reinsurers are, in general, most cost efficient. Some small reinsurers are also able to employ the best available technology and exhibit high pure technical efficiency in their specialized fields, thus partially offsetting their scale inefficiencies. Product diversification (scope) decreases X-efficiency and cost efficiency for small reinsurers, but has no significant impact on medium and large reinsurers. The evidence supports the ES hypothesis, in the sense that cost-efficient reinsurers can charge lower prices without sacrificing profitability. Our results explain the current structure of the global reinsurance market, which is dominated by a few large reinsurers, but in which both diversified and specialized reinsurers play important roles.

We contribute to international business research by showing how the global market for risk transfer is organized. The results illustrate the tradeoff between scale diseconomies and potential gains in X-efficiency, which is relevant for merger and acquisition decisions not only in this industry, but also in other industries which are becoming more global. Hence, our work contributes to the ongoing discussion on the operating efficiency of insurers (Lu, Wang, & Kweh, 2014), operating unit growth (LaPlante & Paradi, 2015), and the systemic relevance of the reinsurance sector (Cummins & Weiss, 2014; Park & Xie, 2014).

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[4] To date, academic research on reinsurance has focused on product demand, contract design, and pricing (see Bernard, 2013 for a review). However, the reinsurance market itself, especially the performance and productivity of reinsurers, are not well researched. Most literature on reinsurance performance applies traditional accounting indicators, such as ROE, ROA, and underwriting ratios (see, e.g., Chen & Hamwi, 2000; Cole & McCullough, 2008; Cole et al., 2010; Outreville, 2012a, 2012b). Cummins and Weiss (2000) provide the first piece of evidence on reinsurers' efficiencies regarding the tradeoff between mean and standard deviation of ROE. Their approach sits in between the traditional accounting performance measurement and the frontier efficiency performance measurement approaches, because they only include one input and one output. In our view, the research gap in reinsurance can partially be attributed to the difficulty to consistently identify reinsurers and the need to combine different datasets in order to get a complete picture of the global reinsurance market. Moreover, the study of efficiency in service businesses is in general difficult and has attracted less attention than industries in which output is more easily quantified.

The paper is organized as follows. In Section 2, we discuss the theoretical background and derive our hypotheses. Section 3 describes our methodology and data. In Section 4, we present the empirical models and results, together with robustness tests. We conclude in Section 5.

2. HYPOTHESIS DEVELOPMENT

2.1 Economies of Scale and the Scale Impact on Efficiency

The theory of economies of scale implies a possible optimal firm size and an optimal market structure. Scale economies (diseconomies) occur when a marginal proportional increase in the scale of all inputs leads to a more (less) than proportional increase in the outputs produced (Clark, 1988; Mansfield, 1970). Hence, competition is Pareto efficient if scale economies become exhausted at a level of output that is a small portion of the market. However, when scale economies are significant and unexhausted at the full extent of the market, a monopoly firm may be able to minimize industry costs and prevent market entry (Panzar & Willig, 1977).

Economies of scale may exist in the reinsurance industry due to expensive IT systems, operating offices, claim settlement operations, and risk management (Cummins & Xie, 2013), thus providing motivation for market consolidation (Cummins, Tennyson, & Weiss, 1999; Lonkevich, 1995). However, size can also lead to inefficiencies, due to agency conflicts, communication costs, and duplication efforts (Cummins & Weiss, 2013). Therefore, scale diseconomies may be present when the disadvantages of scale exceed its advantages. This tradeoff leads to our first hypothesis.

- Hypothesis 1A. There is an inverse-U shaped relationship between reinsurer size and scale efficiency.

An inverse-U shaped relationship between scale efficiency and firm size is found in many industries (see, e.g., Bikker & Gorter, 2011; Cummins & Xie, 2013; Katrishen & Scordis, 1998 for primary insurance; Berger & Humphrey, 1991; Noulas, Ray, & Miller, 1990 for banking). We expect to find that small reinsurers are more likely to operate under increasing returns to scale (IRS),[5] that the largest reinsurers are more likely to operate under decreasing returns to scale (DRS), and that medium-sized reinsurers are more likely to operate under constant returns to scale (CRS). Furthermore, we will look for evidence on the optimal size range, considering the inverse-U shaped relationship between scale efficiency and reinsurer size.

In addition to economies of scale (i.e., scale efficiency), cost efficiency involves other aspects, namely, pure technical efficiency and allocative efficiency. X-efficiency is a combination of pure technical and allocative efficiency. The impact of scale on X-efficiency is important to the reinsurance industry because (1) larger scale enables reinsurers to attract qualified managers and hire experts to develop

[5] In a competitive market, scale economies (diseconomies) and increasing (decreasing) returns to scale are equivalent (Frisch, 1964).

and maintain state-of-the-art technologies for assessing and pricing risk, which enhances X-efficiency and cost efficiency, and (2) large reinsurers are closer to the conditions to apply the law of large numbers, which reduces loss volatility and, thus, enables the use of less capital to manage more risks. Large reinsurers potentially have superior resources for developing and using state-of-the-art technology and thus for being more X-efficient (Cummins & Weiss, 2000). Therefore, we expect that large reinsurers' strong X-efficiency offsets their scale diseconomies and results in an overall positive correlation between size and cost efficiency.

- Hypothesis 1B. There is a positive relationship between reinsurer size and cost efficiency.

2.2 Economies of Scope and Interactions Between Economies of Scale and Scope

Panzar and Willig (1977, 1981) extend the concept of economies of scale to economies of scope, suggesting that firms become more cost efficient by extending their output from only one to two or more products. Economies of scope explain the existence of multi-product firms in a competitive environment. Therefore, in addition to economies of scale and the scale impact on efficiency, any examination of market structure must also consider the economies of scope.

Economies of scope are particularly important to the reinsurance industry because not only can certain inputs—such as IT systems, policy services, and underwriting know-how—be used recurrently for multiple product lines, as in other industries (Teece, 1980), but also a more diversified product portfolio reduces underwriting volatility (Cummins & Weiss, 2013), allowing for higher leverage and less equity capital (Lewellen, 1971). However, product diversification may also negatively influence efficiency. For example, to look at it from the opposite side, more specialized firms will develop core competencies in their core business, leading to decreasing managerial and agency costs (Berger, Cummins, Weiss, & Zi, 2000). Moreover, life and nonlife insurance require different underwriting and pricing techniques, meaning that any benefits from sharing underwriting may be negligible. Furthermore, reinsurers engaged in both primary and reinsurance business may be subject to conflicts of interest with themselves because its primary insurance line will be competing for this sort of business with customers of its reinsurance line.

Berger et al. (2000) and Cummins et al. (2010) develop an empirical framework for economies of scope in the insurance industry by testing the conglomeration hypothesis against the strategic focus hypothesis. Berger et al. (2000) suggest that conglomeration is the dominant strategy for some types of insurers, i.e., larger insurers focusing on personal lines and having a vertically integrated distribution system, whereas a strategic focus is preferred by small insurers focusing on commercial lines and having a nonintegrated distribution system. Elango et al. (2008) suggest that the scope impact on performance depends on an insurer's geographic diversification.

Therefore, it is important to examine whether the impact of product diversification (scope) varies by type of reinsurer. Given that reinsurance is a pure commercial business and that, typically, reinsurers' distribution systems are not integrated (i.e., brokers play an important role), we expect that strategic focus strategies prevail in the reinsurance industry, particularly for small reinsurers. We therefore expect that specialization (diversification) improves (reduces) the X-efficiency and cost efficiency of small reinsurers.

- Hypothesis 2A. Small reinsurers have additional X-efficiency and cost efficiency advantages when they are specialized.

Moreover, product diversification generates additional fixed costs for the new lines of business. Thus, larger size is expected to leverage such costs, which leads us to expect that product diversification increases the size necessary to achieve scale efficiency (Cummins & Xie, 2013); in other words, to achieve the same level of scale efficiency, diversified reinsurer needs to be larger than specialized one.

- Hypothesis 2B. Product diversification increases the size necessary to achieve scale efficiency.

2.3 Efficient Structure

The efficient structure (ES) hypothesis (Choi & Weiss, 2005; Weiss & Choi, 2008) explains market structure from an efficiency perspective. It suggests that the structure of the market in which firms operate is determined by these firms' efficiencies (Demsetz, 1973; Peltzman, 1977). More efficient firms can charge lower prices without sacrificing profitability; hence, they are more competitive. Market consolidation is an expected by-product of efficiency differences, with more efficient reinsurers gaining higher market shares through consolidation (Choi & Weiss, 2005; Weiss & Choi, 2008). From a policymaker's perspective, this consolidation is beneficial for both firms (which operate more efficiently) and consumers (who pay lower prices).

- Hypothesis 3. Cost-efficient reinsurers can charge lower prices without sacrificing profitability.

Choi and Weiss (2005) and Weiss and Choi (2008) develop an empirical framework for the ES hypothesis in the context of the U.S. nonlife insurance market. They find that efficient insurers have higher market shares and argue that this is due to their ability to charge lower prices while generating high profits. Berry-Stoelzle, Weiss, and Wende (2011) find support for the ES hypothesis in the European nonlife insurance market.

In summary, the three hypotheses set out above have important implications for the structure of the global reinsurance market. If an industry's technology allows for economies of scale (scope), the industry will tend to be made up of large (diversified) firms; alternatively, if technology does not allow such economies, small (specialized) firms will tend to dominate (Clark, 1988). Extant scale and scope economies indicate potential for market consolidation from the production perspective, and the competitive pricing advantages enjoyed by cost-efficient firms also lead to that expectation.

3. METHODOLOGY AND DATA

3.1 Data Envelopment Analysis

We use data envelopment analysis (DEA), assuming constant (CRS), variable (VRS), and non-increasing returns to scale (NIRS) to estimate efficient production frontiers separately for each year between 2002 and 2012 (Cook & Zhu, 2014), an empirical approach frequently employed in management research (Atici & Podinovski, 2015; Cook, Liang, & Zhu, 2010). The model specification allows computing the Shephard (1970) input-oriented distance functions, which are reported as the reciprocal of Farrell's (1957) input efficiency measures. The resulting measures of cost (CE), allocative (AE), pure technical (PTE), and scale (SE) efficiency represent the firm's distance from the respective best-practice efficient frontier and are bounded between 0 and 1. Moreover, we estimate X-efficiency (XE) as CE divided by SE or, alternatively, the product of PTE and AE (Cummins et al., 2010; Weiss & Choi, 2008). The reinsurance business model involves globally diversifying risks and, typically, firms have risk exposures worldwide; we thus calculate a one-world frontier for every year.

We exploit the variation of efficiency estimates for the different production frontiers of a reinsurance firm to make inferences about scale economies (Aly, Grabowski, Pasurka, & Rangan, 1990), that is, to discover whether a firm operates under constant returns to scale (CRS), or whether there are scale inefficiencies, represented by increasing (IRS) or decreasing (DRS) returns to scale. Simar and Wilson (2000) suggest a bootstrapping bias-correction procedure for DEA analysis. This approach, however, leads to bootstrapping bias for different frontiers (i.e., CRS, VRS, NIRS) and the results cannot easily be used to make inferences about scale economies This is why we present original efficiency estimates throughout the paper and show results subject to the bootstrapping bias-correction procedure as a robustness test, which also support our conclusions.

To make inferences about the development of productivity and efficiency over time, we employ the input-oriented version of the Malmquist Index of Total Factor Productivity (TFP) (Caves, Christensen, & Diewert, 1982; Färe, Grosskopf, Lindgren, & Roos, 1992) with the consistent bootstrap estimation procedure (Simar & Wilson, 1999). We decompose the TFP into its principal sources of technical and efficiency change. Technical change indicates changes in the production technology from one period to another and, thus, shifts the production frontiers. Efficiency change detects changes in a firm's distance from the best-practice frontier from one period to another. Efficiency change can be further decomposed into PTE change, indicating changes in the VRS frontier, and SE change, implying changes in the distance between the VRS and the CRS frontiers.

Compared to accounting performance measures (e.g., ROE, ROA), the frontier efficiency method has two main advantages: (1) it decomposes efficiency into different components, shedding light on the process through which scale and scope affect efficiency, and (2) it reduces the impact of loss volatility on performance measurement. This is particularly relevant to the reinsurance industry, since the random nature of reinsurance losses can have a large impact on the financial results of a particular year. The ROE (or the mean ROE over a few years) is highly volatile and thus cannot accurately capture a reinsurer's operational performance. The DEA frontier efficiency approach can account for volatility with multiple inputs and outputs. Moreover, extensions of the standard DEA model, such as the loss-smoothing procedure (Cummins & Xie, 2008), are capable of dealing with extreme cases.

After deriving the DEA efficiency scores, we perform DEA second stage regressions as shown in Equation (1) (Cook & Zhu, 2014). Hypotheses predict potential nonlinear relationship between firm size and efficiency. Therefore, we use the natural logarithm of real total assets and its squared term to capture the nonlinear size effects. Each *lnAsset* is centered at the mean of all firm-year *lnAsset* values to avoid multicollinearity between size and its square, $\mathrm{l}nAsset_{centered_{i,t}} = \mathrm{lnAsset}_{\mathrm{i,t}} - \overline{\mathrm{lnAsset}}$, where $\overline{\mathrm{lnAsset}}$ is the average of all firm-years, and all asset values are inflation adjusted at 2012. The dummy variable *composite* measures a reinsurer's product diversification across life and nonlife business. The dummy variable *conglomerate* measures the reinsurer's product diversification across reinsurance and primary insurance. *X* is a series of control variables, including leverage ratio (total liabilities divided by total equity and surplus), affiliation status (1 if the reinsurer is an unaffiliated single firm), headquarter location dummies (market fixed effects), and year dummies (time fixed effects)[6]. After controlling for the market and year fixed effects, we use random effects panel regressions legitimated by Hausman and log-likelihood ratio tests.[7] We conduct firm fixed effects regressions as a robustness test, the results of which are consistent.

$$Efficiency_{i,t} = \beta_0 + \beta_1 Size_{i,t} + \beta_2 {Size_{i,t}}^2 + \beta_3 Composite_i + \beta_4 Conglomerate_i + \beta_j X_{i,t} + \varepsilon_{i,t} \quad (1)$$

3.2 Inputs, Outputs, and Prices

For input quantities we use labor (number of employees), materials and business services, and total equity capital (in real values at 2012). The number of employees is from annual reports of the respective reinsurers. We use the annual average wages for the insurance sector (banking, if insurance is not available) in respective country-years as the price of labor. The wage information is obtained from the ILO Main Statistics and October Inquiry databases.[8] The quantity of materials and business

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[6] Supplementary Material D presents the distribution of our sample over years and by geographical regions. We group the domiciled locations of reinsurers into four reinsurance hubs and six additional regional markets. The reinsurance hubs are Western Continental Europe, North America, Bermuda, and London (Holzheu & Lechner, 2007). The additional regional markets include Asia Developed, Asia Emerging, Africa, Eastern Europe, Latin America, and Middle East.

[7] The Hausman test discriminates fixed from random effects models and gives the Chi-square statistic of 11.71 (p-value of 0.63). The log-likelihood ratio test discriminates random effects models from pooled OLS regressions and gives Chi-bar-square statistic of 94.52 (p-value of 0.00).

[8] Wage is not available for all country-years, so we proxy the price of labor by adjusting the nearest available data point to the previous or later year using CPIs.

services is calculated as operating expenses minus employee costs, following the procedure in Cummins and Weiss (2013). We proxy the price of materials and business services by the consumer price indices (CPI) of respective country-years. Production price indices (PPI) are used as a robustness test. We approximate total equity capital by capital and surplus in Best's Insurance Reports (A.M. Best, 2002–2012). We use the average realized ROE of respective years as the price of equity capital. The yearly rates of total return from Morgan Stanley Capital International (MSCI) Indices in respective countries are used as a robustness test.[9]

For output quantities we use total invested assets and losses (both in real values at 2012). These represent a reinsurer's two major functions: risk pooling (risk bearing) and financial intermediation. Reinsurers also act as think tanks and serve as consultants to primary insurers; however, they do not usually charge for such services, but offer them as a door into acquiring new business. Therefore, the consulting function is integrated into, and reflected by, the output of loss. We approximate the total invested assets by the total investments in Best's Insurance Reports (A.M. Best, 2002–2012). We calculate the losses with the loss-smoothing procedure in Cummins and Xie (2008); also documented in Supplementary Material A (all supplementary materials are available from the authors upon request). This procedure is particularly well-suited for losses of P&C and reinsurance, which are highly volatile. Premiums are sometimes used as an alternative output to loss, since premiums represent the business volume produced. However, Yuengert (1993) points out that premiums represent price times quantity, instead of just quantity. We include a model relying on premiums, instead of smoothed losses, as a robustness test (Cummins & Weiss, 2013), the results of which are consistent with our core models.

3.3 Data and Summary Statistics

The global reinsurance market is dominated by professional reinsurers[10] (Holzheu & Lechner, 2007). Like Cummins and Weiss (2000), we found it difficult to discover a single coherent data source that contains all the information necessary to conducting a reinsurance efficiency study. We thus use four sources: (1) Best's Insurance Reports (A.M. Best, 2002–2012) database, which includes general and financial information on all non-U.S. reinsurers; (2) Standard & Poor's Global Reinsurance Highlights (Standard & Poor's Rating Services, 2003–2013), which includes a global reinsurance survey for each year and containing the most complete list of active reinsurers worldwide, which we use to identify U.S. reinsurers and fill in information missing from Best's Insurance Reports; (3) annual reports of reinsurers (2002–2012), which is our major source for number of employees and

[9] A rolling window of 10-year averages is used. The remaining negative values are censored at 0. The MSCI Indices are obtained from the Thomson DataStream database.

[10] A professional reinsurer is a firm for which reinsurance is the major business, as opposed to a primary insurer, which may also engage in reinsurance as a sideline.

financial information of U.S. reinsurers; and (4) the Best's Special Report on Global Reinsurance (A.M. Best, 2013), from which we use the list of top 50 reinsurers to fill in missing values.

Different approaches are taken in differentiating professional reinsurers from primary insurers (Beaver, McNichols, & Nelson, 2003; Cole & McCullough, 2006; Cummins & Weiss, 2000). Cole and McCullough (2008) find that the criteria used to identify reinsurers significantly influences empirical outcomes–a standard empirical selection bias problem–and that efforts to unify the definition of reinsurer are inconclusive. Whether a company is a reinsurer or a primary insurer is much less clear-cut than whether a company is a life or a nonlife insurer. This is because some insurers sell both primary and reinsurance, and because the reinsurance transactions often covers a significant share of transactions between affiliated firms (e.g., subsidiaries reinsure their portfolios with their headquarters). Because we are studying the global reinsurance market, we are interested in professional reinsurers, that is, insurers that engage in reinsurance on the open market as their major business. This paper does not aim to solve the reinsurance definition problem, but instead controls for the influence that the selection criteria could have on the empirical results.

Therefore, we follow a four-step algorithm to generate our sample of professional reinsurers. First, an insurer's reinsurance premiums written must account for more than 50% of its total premiums written[11] (Beaver, McNichols, & Nelson, 2003). Second, we eliminate multiple reinsurers within one reinsurance group and identify one unique entity that reflects the reinsurance business of the group. We focus on the reinsurance business share,[12] setting the cut-off threshold at 50%. Only those entities above the threshold are considered as representative of the reinsurance group. Third, if multiple entities meet the representation criterion within a group, we select the one that is used as the A.M. Best Rating Unit, which separates out the entity best representing the way the insurance group operates and manages the business and eliminates reinsurance transactions within a group or among affiliates. Fourth, we exclude Lloyd's syndicates, captives, reinsurance pools, and "bridge reinsurers" that retain less than 20% of their gross premiums written.[13] We employ year 2012 data for our identification procedure, and due to data limitations, assume consistency back to earlier years. Reinsurers that existed before 2012, but were not active in 2012, were usually bought by one of the

[11] In most cases, gross premiums are considered; if these are not available, we take net premiums.

[12] Gross reinsurance premiums written by the identified entity divided by gross reinsurance premiums written by the group. If gross premiums are not available, we take net reinsurance premiums.

[13] Lloyd's syndicates usually operate only core functions (e.g., underwriting) by themselves and outsource supporting functions (e.g., HR, IT) to Lloyd's market services. This practice leads to these firms having a very small number of employees. Thus, we cannot consider Lloyd's syndicates as stand-alone firms. Only one-third of the business done by Lloyd's market as a whole, however, is reinsurance and thus they do not meet the criteria of professional reinsurer. Captives, reinsurance pools, and "bridge reinsurers" have operating models different from those of traditional reinsurers, and their financial results are not fully comparable to those of a traditional reinsurer. Thus, we do not include them in our DEA analysis.

other reinsurers in our sample, instead of going bankrupt.[14] Thus, the poor performance of acquired reinsurers becomes an integral part of the acquiring reinsurers. Therefore, we consider the survivorship bias to be minimal.

Our final sample contains 116 professional reinsurers and 841 firm-years.[15] The total net reinsurance premiums written by our sample in 2012 is USD 164 billion, representing 91% of the professional reinsurance market[16] and 71% of the total global reinsurance market.[17] The business of reinsurers in our sample varies from treaty to facultative reinsurance and from proportional to non-proportional reinsurance; however, detailed information regarding product mix is not available. The dataset covers the period from 2002 to 2012. We exclude observations with extreme values (i.e., outside the 1 and 99 percentiles) in operating expense ratio and business services ratio.[18] These reinsurers with extreme values are usually startups that do not yet underwrite reinsurance or runoff reinsurers, which are not comparable to and not in competition with regular reinsurers. Table 1 shows summary statistics for our sample. There is a great deal of variation in firm size and underwriting ratios (i.e., loss ratios and expense ratios): 45% of reinsurers engage in both life and nonlife reinsurance; 16% of professional reinsurers write significant amounts of primary insurance business, having a reinsurance premium share between 50% and 95%; 25% of reinsurers operate as unaffiliated single firms, while the remaining firms operate as groups or affiliates with others. The average leverage ratio is 2.75, which is slightly higher than the leverage ratio of 2.13 found a decade ago by Cummins and Weiss (2000).

[14] We identified 14 cases that the professional reinsurers existed before 2012, but were not active in 2012, by reviewing the top 40 reinsurers each year in Global Reinsurance Highlights (2003–2012). All of them were bought by other reinsurers in our sample, e.g., GE insurance solutions was bought by Swiss Re. Cummins and Weiss (2000) also indicate that mergers and acquisitions of reinsurers usually happen within the reinsurance industry, with a purpose of risk diversification.

[15] Some values are missing from our dataset due to the unavailability of some inputs and outputs from any of our four data sources. The most common missing values are number of employees. We filled in the missing information using predicted values that we extrapolated based on observed data and performed a robustness test by using only observed data, i.e., excluding observations with missing values, the results of which are consistent with the results of our main analysis.

[16] We use the total net reinsurance premiums written (USD 179.22 billion) from S&P Global Reinsurance Survey 2012 as the size of the professional reinsurance market (Standard & Poor's Rating Services, 2013).

[17] We use Swiss Re's estimation of USD 230 billion in global reinsurance premiums in 2012 as the size of the global reinsurance market, which includes reinsurance assumed by both professional reinsurers and primary insurers (Swiss Re, 2013).

[18] The operating expense ratio is defined as operating expenses divided by net premiums written. The business services ratio is defined as cost of materials and business services divided by total operating expenses. This winsorizing excludes 4% of firm-year observations from our sample.

Table 1
Summary statistics

	Unit	Mean	Std. Dev.	Min.	10th PTCL	Median	90th PTCL	Max.
Panel A: Input Quantities								
Number of employees	1	538.5	1,572.5	2	38	122	1,038	11,702
Quantity of materials and business services	1,000	539,130	2,008,515	166.5	7,838	94,785	707,956	19,888,900
Equity capital and surplus [a]	1,000	1,919,850	4,845,149	626.7	44,592	416,072	4,223,843	39,919,200
Panel B: Input Prices								
Wage[a]	1	47,215.6	26,137.7	1,394	13,782	48,642	71,741	138,017
CPI with base year of 2012	%	88.5	12.1	32.2	76.1	91.5	100	101.3
PPI with base year of 2012[b]	%	87.4	13.2	32.2	70.7	91.2	100	112.8
Realized ROE	1	0.099	0.17	-2.27	-0.011	0.099	0.23	1.69
MSCI yearly rates of equity total returns	1	0.14	0.15	-0.058	0.011	0.11	0.25	1.48
Panel C: Output Quantities								
Total invested assets[a]	1,000	8,332,645	33,878,375	926.0	71,407	844,445	11,022,524	277,719,424
Smoothed loss[a]	1,000	1,467,686	5,055,169	730.5	17,791	241,395	2,351,311	43,623,480
Net premiums written[a]	1,000	2,110,135	7,197,933	945.7	27,166	369,349	3,613,961	66,319,992
Panel D: Others								
Total assets[a]	1,000	11,581,832	44,005,533	2,149.8	96,468	1,276,144	15,440,389	342,956,544
Composite[c,d]	dummy	0.45	0.50	0	0	0	1	1
Conglomerate[c,e]	dummy	0.16	0.37	0	0	0	1	1
Unaffiliated[c,f]	dummy	0.25	0.43	0	0	0	1	1
Leverage ratio	1	2.75	3.23	0.054	0.56	1.77	5.84	34.4
Loss ratio	%	67.0	25.0	1.20	43.2	65.1	88.6	284.5
Smoothed loss ratio	%	65.9	6.87	44.5	57.3	65.7	74.6	96.8
Operating expenses ratio	%	30.6	11.1	2.70	17.3	29.8	43.8	82.1
Smoothed underwriting profit ratio	%	3.44	11.1	-59.1	-7.23	3.92	15.6	40.0
Market growth	%	6.72	8.38	-8.10	-2.90	7.30	14.4	33.1
Price of reinsurance (inverse of smoothed loss ratio)[g]	1	1.53	0.16	1.03	1.34	1.52	1.75	2.25
Number of observations	841							

[a]In USD and inflation adjusted at 2012.
[b]For the following countries or regions PPIs are not available, and are thus replaced by CPIs: Barbados, Bermuda, Cayman Islands, Dominican Republic, Ghana, Kenya, Lebanon, and Nigeria.
[c]Information is only available for the year of 2012, and we assume the status is unchanged for one firm over our sample period.
[d]Composite equals 1 if the reinsurer engages in both life and nonlife business.
[e]Conglomerate equals 1 if the primary insurance premium takes more than 5% of the total premium written.
[f]Unaffiliated equals 1 if the reinsurer is an unaffiliated single firm.
[g]For detailed discussions, see Choi and Weiss (2005), Cummins and Danzon (1997), and Winter (1994).

4. EMPIRICAL ANALYSIS AND RESULTS

4.1 Efficiency and Productivity Estimations

Table 2 presents the results of the input-oriented DEA analyses. We show average efficiency scores for three sizes of firms (i.e., small, medium, and large) with equal number of firm-years in each category. Small reinsurers are significantly less scale efficient than medium and large reinsurers. Regarding PTE and AE, both small and large reinsurers are more efficient than medium reinsurers. XE demonstrates the same pattern as PTE and AE: small reinsurers are more (less) X-efficient than medium (large) reinsurers. Combining the results of SE, PTE, and AE, we observe that CE scores increase with firm size, indicating initial support for Hypothesis 1B.

Table 2
Mean efficiency scores by firm size

Firm size categories	**Mean efficiency scores**					**N**
	SE	**PTE**	**AE**	**XE**	**CE**	
Small (total assets < 539M)	0.648	0.657	0.771	0.444	0.281	281
	(0.232)	*(0.221)*	*(0.228)*	*(0.188)*	*(0.162)*	
Medium (539M < total assets < 3.35B)	0.899	0.582	0.687	0.385	0.353	280
	(0.125)	*(0.216)*	*(0.232)*	*(0.180)*	*(0.187)*	
Large (total assets > 3.35B)	0.931	0.704	0.731	0.506	0.471	280
	(0.105)	*(0.260)*	*(0.204)*	*(0.241)*	*(0.236)*	
Total	0.826	0.648	0.706	0.445	0.368	841
	(0.207)	*(0.238)*	*(0.222)*	*(0.210)*	*(0.212)*	
P-values of mean difference ANOVA F-tests[a]	0.000	0.000	0.060	0.000	0.000	

Notes: We present arithmetic means of respective efficiency scores, with standard deviations in parentheses.
[a]We test whether the average efficiency scores in different size categories are equal to each other.

Table 3 shows that the reinsurance industry's total productivity improved by 30% from 2002 to 2012. This improvement was due to (1) a technology frontier improvement of 16%, and (2) a pure technical efficiency change of 13% (with significance level of 0.12), suggesting that less efficient reinsurers adopted best practices. We also perform TFP analyses for the two sub-periods of 2002–2007 and 2008–2012, and for every adjacent years. The results are consistent with the overall trend shown by the whole sample period: a continuous improvement in total productivity in both sub-periods and in 8 out of 10 adjacent years (see Supplementary Material B).

Table 3
Malmquist TFP analyses

Start Year	**End Year**	**TFP Change**	**Std. Dev.**	**Technical Change**	**Std. Dev.**	**PTE Change**	**Std. Dev.**	**SE Change**	**Std. Dev.**	**N**
2002	2012	1.303**	0.765	1.164***	0.219	1.130[a]	0.515	0.985	0.168	40
2002	2007	1.205*	0.797	0.949	0.232	1.149**	0.422	1.105**	0.285	44
2008	2012	1.100*	0.484	1.226***	0.321	0.935**	0.227	0.976	0.196	71

Notes: We perform two-side T-tests to detect whether the mean of respective changes are significantly different from 1. *, **, *** denote significance levels at the 10%, 5%, and 1%, respectively. aP-value equals 0.12.

4.2 Economies of Scale

We follow Aly et al. (1990) to determine whether scale-inefficient firms operate under IRS or DRS. Firms with a SE score equal to 1 operate under CRS. Table 4 shows that 68% of reinsurers operate under IRS, 11% under CRS, and 21% under DRS. Large reinsurers are more likely to exhibit CRS and DRS, and small reinsurers have a higher proportion of IRS entities. We follow the strategy of Cummins and Zi (1998) and Cummins and Xie (2013) to identify the size threshold at which scale economies are exhausted. The results in Columns 1 to 6 of Table 4 suggest that there are two critical points for total assets: below USD 4.3 billion, the majority of reinsurers (over 74%) operate under IRS; none of the insurers with assets above USD 15.5 billion operate under IRS, but 71% of these operate under DRS. This finding supports Hypothesis 1A. Comparing these observations with the primary insurance industry, we note that the asset size at which reinsurer scale economies are exhausted is larger than that for life insurers' (USD 1 billion; see Cummins & Zi, 1998) and that for nonlife insurers' (USD 137.1 million; see Cummins & Xie, 2013).[19] The global nature of the reinsurance business may explain these differences.

Table 4
Returns to scale and mean scale efficiency scores by firm size

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Total Assets	**IRS**	**CRS**	**DRS**	**IRS**	**CRS**	**DRS**	**Mean of SE**	**Std. Dev. of SE**	**N**
Panel A: Size Deciles Firm-Years Percentage									
< 97 M	81	4	0	95%	5%	0%	0.545 (N.A.)	0.237	85
97M–237M	78	3	3	93%	4%	4%	0.679***	0.228	84
237M–435M	75	5	4	89%	6%	5%	0.682	0.207	84
435M–795M	79	4	1	94%	5%	1%	0.809***	0.174	84
795M–1.28B	79	4	1	94%	5%	1%	0.897***	0.124	84
1.28B–2.04B	66	11	7	79%	13%	8%	0.911	0.114	84
2.04B–4.30B	62	10	12	74%	12%	14%	0.951***	0.062	84
4.30B–7.60B	32	16	36	38%	19%	43%	0.966*	0.046	84
7.60B–15.5B	20	14	50	24%	17%	60%	0.963	0.051	84
> 15.5B	0	24	60	0%	29%	71%	0.858***	0.151	84
Total	572	95	174	68%	11%	21%	0.826	0.207	841
Panel B: Size Vigintiles[a]									
2.04B–2.90B	31	6	5	74%	14%	12%	0.939	0.067	42
2.90B–4.30B	31	4	7	74%	10%	16%	0.963*	0.056	42

Notes: *, **, *** denote significance levels at 10%, 5%, and 1% of mean difference t-tests between two adjacent size classes. The first SE mean is marked with N.A. because there is no smaller category to compare with. [a] We only show the vigintile's results that are critical to identify the optimal size range. The complete results are available from the authors upon request.

To directly test Hypothesis 1A and to identify a robust optimal scale range, we advance the conventional method by the following three analyses. First, we analyze average SE scores by size deciles and vigintiles. The results in Columns 7 and 8 of Table 4 suggest that reinsurers with total assets between USD 2.9 and 15.5 billion (inflation adjusted at 2012) are, on average, significantly

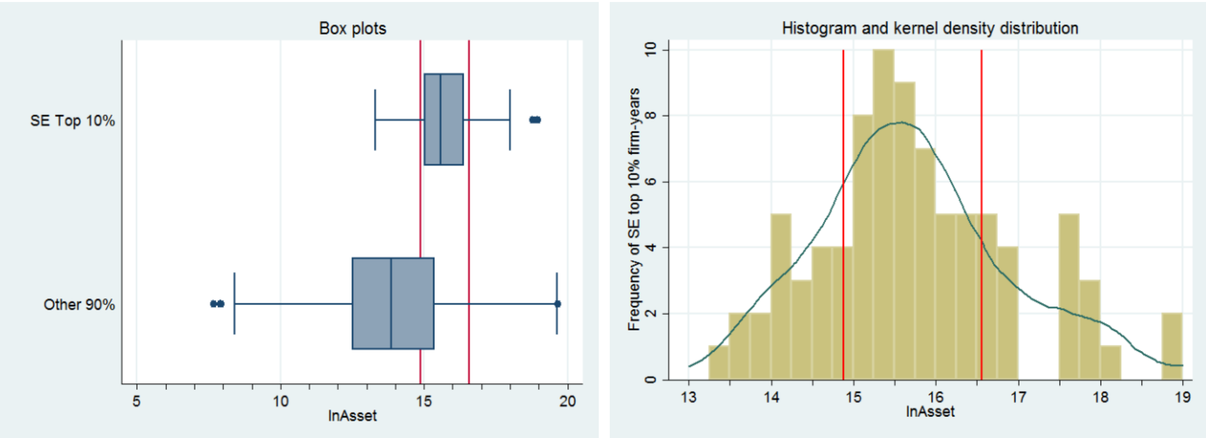
[19] The thresholds are larger than those usually found for other services industries such as banking. (Clark, 1988).

more scale efficient than larger or smaller reinsurers. The existence of an optimal size range supports Hypothesis 1A. The range of USD 12.6 billion is a wide one in terms of absolute value; however, it is only 28.6% of one standard deviation of our sample reinsurers' total assets (USD 44.0 billion). It is thus a relatively accurate range considering the whole size spectrum of reinsurers.

Second, we apply the DEA second-stage regression to SE scores, as defined in Equation (1). The results in Column 2 of Table 5 show that SE increases with firm size at a decreasing rate, then reaches optimal size, and subsequently decreases with firm size. The pattern confirms H1A. Third, we obtain the predicted SE scores from the above regression and extract the top 10% scale-efficient firm-year observations to identify a corresponding optimal asset range (see Figure 1). A similar approach is found in Berger and Humphrey (1991) and McAllister and McManus (1993). The two vertical lines with USD 2.9 billion and 15.5 billion mark the asset range identified by the decile and vigintile analyses. The box plots show that for the top 10% scale-efficient observations, total asset values within the 25th and 75th percentiles fall into the identified optimal size range. The histogram suggests that around 60% of the top 10% scale-efficient observations have total assets within the identified optimal size range. The inspection of the visualized kernel density distribution serves as a further indicator of the existence and robustness of the identified optimal size range.

Based on the three additional analyses, we adjust the size range obtained from the conventional approach (Cummins & Zi, 1998; Cummins & Xie, 2013) and conclude that an optimal size range for reinsurers is between USD 2.9 billion and 15.5 billion in total assets. The estimated optimal size range is based on scale efficiency and does not account for the impact of scale on other components of cost efficiency. In general, our evidence supports the theoretical predictions of economies of scale in the global reinsurance market. The data suggest that firms in the optimal size range have a higher probability of being scale efficient than firms outside this range.

Figure 1 Optimal size range



Notes: The left figure shows box plots of *lnAsset* for the top 10% scale-efficient firm-years compared with the 90% non-scale-efficient firm-years. The right figure shows the histogram and estimated kernel density of *lnAssets* for the same top 10% scale-efficient observations. The two vertical lines in both figures show the optimal size range obtained from the decile and vigintile analyses. The asset values used are in thousand US dollars.

Table 5
Determinants of efficiencies

Variables	(1) SE	(2) SE	(3) PTE	(4) PTE	(5) AE	(6) AE	(7) XE	(8) XE	(9) CE	(10) CE
lnAsset	0.0331***	0.0355***	-0.0201	-0.0202*	0.0359***	0.0359***	0.0185*	0.0173*	0.0313***	0.0314***
	(0.00869)	(0.00652)	(0.0137)	(0.0112)	(0.00861)	(0.00856)	(0.0101)	(0.00937)	(0.00917)	(0.00926)
$lnAsset^2$		-0.00956***		0.00741***		-0.000356		0.00573**		-0.000743
		(0.00159)		(0.00244)		(0.00204)		(0.00237)		(0.00201)
Composite	0.00376	0.0135	0.0205	0.0100	-0.0762***	-0.0758***	-0.0389*	-0.0456**	-0.0280	-0.0271
	(0.0185)	(0.0151)	(0.0347)	(0.0329)	(0.0234)	(0.0233)	(0.0222)	(0.0218)	(0.0196)	(0.0199)
Conglomerate	0.00418	0.0185	0.0231	0.0108	-0.0358	-0.0350	-0.0277	-0.0363	-0.0283	-0.0272
	(0.0251)	(0.0184)	(0.0534)	(0.0479)	(0.0361)	(0.0358)	(0.0362)	(0.0350)	(0.0297)	(0.0301)
Leverage ratio	0.00310*	0.00466***	0.0165***	0.0161***	-0.00242	-0.00233	0.00980**	0.00922**	0.0107**	0.0108**
	(0.00177)	(0.00151)	(0.00214)	(0.00218)	(0.00401)	(0.00409)	(0.00485)	(0.00449)	(0.00467)	(0.00478)
Unaffiliated	-0.0616**	-0.0273	0.0596	0.0330	0.00488	0.00617	0.0427	0.0214	0.00580	0.00848
	(0.0301)	(0.0276)	(0.0460)	(0.0451)	(0.0271)	(0.0277)	(0.0270)	(0.0277)	(0.0248)	(0.0268)
Market fixed effects/year fixed effects/constant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Overall R^2	0.513	0.577	0.283	0.353	0.379	0.380	0.419	0.454	0.563	0.562
Observations/number of reinsurers	841/116									

Note: We present the results of random effects panel regressions with robust standard errors clustered at firm level provided in parentheses; *, **, *** denote the significant differences of the regression coefficients from 0 at the 10%, 5%, and 1% levels, respectively.

4.3 Scale Impact on Efficiency

To assess the impact of scale on other efficiency measures, we estimate Equation (1) with PTE, AE, XE, and CE scores, as shown in Columns 3 to 10 of Table 5. The results in Column 10 confirm Hypothesis 1B by showing that reinsurers' cost efficiency scores increase along with firm size. The PTE results in Column 4 suggest a U-shaped relationship between firm size and PTE. Both small and large reinsurers are more likely to employ the best technologies than are medium-sized reinsurers. The results in Columns 5 and 6 suggest a positive linear relationship between firm size and AE. The X-efficiency results in Columns 7 and 8 show the combined effects of PTE and AE.

Large reinsurers are indeed the most cost efficient because they define the best-practice technology frontier and best allocate their costs among different inputs. Their advantages in XE offset the extant scale inefficiencies (scale diseconomies). Small reinsurers are also able to exploit the best-practice technologies (Sui & Baum, 2014); albeit not to an extent sufficient to offset the inefficiencies in terms of scale and cost allocation. The superior PTE of some small reinsurers may result from their expertise in special segments (a focused strategy), which we will test in a later section of this paper. With respect to the control variables, there is a positive correlation between leverage and efficiency, and no significant correlation between firm affiliation type and efficiency. Reinsurers based in Western Continental Europe, the world reinsurance center, are more cost efficient than reinsurers in most of the other regions.

In addition to the standard DEA second-stage regressions, we employ the Granger causality test to show whether a reinsurer's scale drives cost efficiency (Berger & DeYoung, 1997; Casu & Girardone, 2009) or vice versa. The use of Granger causality tests is an innovative approach in insurance frontier efficiency analyses. Based on Equation (2), we test the null hypothesis ($H.A_0$) that size does not Granger cause higher efficiency, i.e., $\beta_{1,1} = \beta_{1,2} = \cdots = \beta_{1,n} = 0$. Based on Equation (3), we test for reverse causality ($H.B_0$), i.e., efficiency does not Granger cause greater size, i.e., $\beta_{3,1} = \beta_{3,2} = \cdots = \beta_{3,n} = 0$. We perform nested F-tests for each regression with *n=1,2,…8* and show the resulting p-values in Table 6, where *n* represents the number of lagged *Size* and *CE* variables included in the equations, respectively. The results reject $H.A_0$ for all *n* except *n=8* at the 95% confidence level and accept $H.B_0$ for all *n*.[20] Therefore, we conclude that size Granger causes greater cost efficiency.

$$CE_{i,t} = \beta_0 + \sum \beta_{1,n} Size_{i,t-n} + \beta_2 Composite_i + \beta_3 Conglomerate_i + \sum \beta_{3,n} CE_{i,t-n} + \beta_j X_{i,t} + \varepsilon_{i,t} \quad (2)$$

$$Size_{i,t} = \beta_0 + \sum \beta_{1,n} Size_{i,t-n} + \beta_2 Composite_i + \beta_3 Conglomerate_i + \sum \beta_{3,n} CE_{i,t-n} + \beta_j X_{i,t} + \varepsilon_{i,t} \quad (3)$$

[20] We consider the optimal lag length for both equations by using the AIC/BIC criteria. The results suggest that AIC/BIC is minimized at n=1 for Equation 2 and at n=2 for Equation 3.

Table 6
Granger causality test for size-CE relationship

	n=1	n=2	n=3	n=4	n=5	n=6	n=7	n=8
	P-Values of Nested F-Tests							
$H.A_0$ in Equation (2)	0.000	0.002	0.050	0.003	0.003	0.101	0.050	0.204
$H.B_0$ in Equation (3)	0.678	0.355	0.322	0.343	0.234	0.549	0.753	0.231
Number of observations	706	586	474	373	289	214	149	108

4.4 Economies of Scope

We follow an approach similar to that of Cummins et al. (2010) in assessing the scope impact on efficiencies so as to make inferences about economies of scope.[21] The results in Columns 9 and 10 of Table 5 show that product diversification, both *composite* (life/nonlife) and *conglomerate* (primary-/reinsurance), does not have a significant impact on reinsurer cost efficiency. However, the results in Columns 5 to 8 suggest that composite strategies (i.e., underwriting both life and nonlife business) increase the difficulty of cost allocation of multiple inputs, and thus decrease AE as well as XE.

We further examine economies of scope for different sizes of reinsurers (Berger et al., 2000) by sorting our sample into small, medium, and large reinsurers as in Table 2. We focus on X-efficiency, which excludes economies of scale and thus allows assessing the pure economies of scope (Cummins et al., 2010). The results in Column 1 (Column 6) of Table 7 suggest that the negative impact of product diversification on XE (CE) only holds for small reinsurers, for which specialized strategies are more X-efficient (cost-efficient) than composite strategies. The observation supports Hypothesis 2A in the sense that small reinsurers are better off when specialized (Sui & Baum, 2014). The results in Columns 2, 3, 7, and 8 show that for medium and large reinsurers, the impact of product diversification is insignificant. Alternatively, we test Hypothesis 2A by adding dummy indicators for small-specialized and large-diversified reinsurers, as shown in Columns 4 and 5 (Column 9 and 10) of Table 7. The results confirm that small specialized reinsurers are more X-efficient (cost-efficient); neither analysis finds any particular X-efficiency (cost-efficiency) advantage for large diversified reinsurers. These observations explain why both specialized and diversified reinsurers can co-exist in the global reinsurance market.

[21] An alternative way of analyzing economies of scope is to show that the cost of jointly producing multiple outputs is smaller than the cost of separately producing these outputs (Berger et al., 2000). We cannot adopt this approach because our data do not allow separating the separation of losses from life insurance from those of nonlife business, nor the losses from primary insurance from those of reinsurance. This approach furthermore requires specifying a cost function, providing significant room for model misspecification risk.

Table 7
Scope impact on different size reinsurers

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Subsamples	**Small**	**Medium**	**Large**	**Full Sample**		**Small**	**Medium**	**Large**	**Full Sample**	
Variables	**XE**	**XE**	**XE**	**XE**		**CE**	**CE**	**CE**	**CE**	
Small*Specialized				0.0882***					0.0574***	
				(0.0219)					(0.0198)	
Large*Composite				0.0420					0.0120	
				(0.0341)					(0.0297)	
Small*Focused					0.0760***					0.0468**
					(0.0204)					(0.0184)
Large*Conglomerate					0.0404					-0.00497
					(0.0585)					(0.0382)
Composite	-0.109***	-0.0100	-0.0752	-0.0256	-0.0403*	-0.0518**	0.00719	-0.0843	-0.00906	-0.0232
	(0.0263)	(0.0381)	(0.0620)	(0.0259)	(0.0213)	(0.0225)	(0.0394)	(0.0616)	(0.0254)	(0.0200)
Conglomerate	-0.00687	-0.0348	-0.0668	-0.0350	-0.0315	-0.0582	-0.0325	-0.0562	-0.0248	-0.0184
	(0.0440)	(0.0413)	(0.0637)	(0.0360)	(0.0387)	(0.0510)	(0.0401)	(0.0601)	(0.0309)	(0.0337)
lnAsset_centered	-0.125**	0.0192	-0.0480	0.0270***	0.0273***	0.0266	0.0439*	-0.0766	0.0367***	0.0368***
	(0.0506)	(0.0220)	(0.0778)	(0.00992)	(0.0100)	(0.0367)	(0.0238)	(0.0824)	(0.00992)	(0.00985)
$\text{lnAsset\_centered}^2$	-0.0134*	0.0345	0.0156	0.00456**	0.00454*	-0.000311	0.00538	0.0172	-0.00149	-0.00154
	(0.00696)	(0.0372)	(0.0144)	(0.00229)	(0.00235)	(0.00545)	(0.0352)	(0.0145)	(0.00192)	(0.00194)
Leverage ratio	0.0410***	0.00323	0.0172***	0.00927**	0.00965**	0.0276**	0.00321	0.0207***	0.0106**	0.0110**
	(0.0110)	(0.00384)	(0.00478)	(0.00424)	(0.00411)	(0.0112)	(0.00408)	(0.00481)	(0.00462)	(0.00453)
Unaffiliated	-0.0266	-0.0328	0.0671	0.0153	0.0125	-0.00163	-0.0377	0.123	0.00564	0.00279
	(0.0271)	(0.0335)	(0.106)	(0.0262)	(0.0274)	(0.0259)	(0.0370)	(0.0893)	(0.0264)	(0.0276)
Market FE/year FE /constant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Overall R^2	0.496	0.518	0.531	0.466	0.461	0.607	0.561	0.564	0.566	0.561
Observations	281	280	280	841	841	281	280	280	841	841
Number of reinsurers	54	54	38	116	116	54	54	38	116	116

Notes: We present the results of random effects panel regressions with robust standard errors clustered at firm level provided in parentheses; *, **, *** denote the significant differences of the regression coefficients from 0 at the 10%, 5%, and 1% levels, respectively.

4.5 Interactions Between Economies of Scale and Scope

We conduct a multinomial logistic regression (Greene, 2012) to assess drivers of economies of scale (returns to scale (RTS)) as specified in Equation (4) (Cummins & Xie, 2013). All independent variables used in Equation (4) are the same as those in Equation (1). The results in Table 8 indicate that, in general, product-diversified reinsurers are more likely to operate under IRS than are specialized reinsurers, and are less likely to operate under DRS, though the results are less significant. Similar patterns are also found in primary insurance (Cummins & Xie, 2013). One explanation is that product diversification increases the size required for a firm to become scale efficient, such that firms that expand their scope need time to grow to the new size optimal for their broader scope (Cummins & Xie, 2013).[22] The more diversified a firm, the larger it needs to be to reach scale efficiency. Firms originally operating under DRS become IRS or CRS after increasing scope, and firms originally operating under CRS become IRS. This also explains the insignificant impact of diversification on the probability of operating under CRS and on scale efficiency. The finding supports Hypothesis 2B.

$$RTS_{i,t} = \beta_0 + \beta_1 Size_{i,t} + \beta_2 {Size_{i,t}}^2 + \beta_3 Composite_i + \beta_4 Conglomerate_i + \beta_j X_{i,t} + \varepsilon_{i,t} \quad (4)$$

Table 8
Determinants of returns to scale

Variables	**IRS**	**CRS**	**DRS**	**IRS**	**CRS**	**DRS**
lnAsset_centered	-0.153***	0.0167***	0.137***	-0.163***	0.0199**	0.143***
	(0.0267)	(0.00646)	(0.0254)	(0.0511)	(0.00801)	(0.0501)
$lnAsset\_centered^2$				-0.00564	0.00341**	0.00222
				(0.00922)	(0.00172)	(0.00838)
Composite	0.0474*	-0.00937	-0.0380	0.0467	-0.0106	-0.0361
	(0.0283)	(0.0116)	(0.0239)	(0.0337)	(0.0156)	(0.0279)
Conglomerate	0.0731***	-0.00826	-0.0648***	0.0807**	-0.0164	-0.0643*
	(0.0260)	(0.0137)	(0.0218)	(0.0366)	(0.0140)	(0.0331)
Leverage ratio	0.0127**	0.00502***	-0.0178***	0.01000	0.00540***	-0.0154*
	(0.00608)	(0.00159)	(0.00642)	(0.00839)	(0.00153)	(0.00839)
Unaffiliated	-0.0333	0.0347	-0.00134	-0.0165	0.0294	-0.0128
	(0.0440)	(0.0355)	(0.0409)	(0.0416)	(0.0364)	(0.0401)
Market FE/year FE/constant	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo R^2		0.438			0.451	
Observations/number of reinsurers			841/116			

Notes: We present the marginal effects of multinomial logistic regressions with robust standard errors clustered at firm level provided in parentheses; *, **, *** denote the significant differences of the regression coefficients from 0 at the 10%, 5%, and 1% levels, respectively.

The results in Table 8 further support Hypothesis 1A, that is, the probability of operating under IRS negatively relates to firm size and the probability of operating under CRS and DRS positively relates to firm size, conditioning on observables, market fixed effects, and year fixed effects. The impact of

[22] Cummins and Xie (2013) use this explanation for the impact on IRS. We expand it to DRS and CRS.

size on the probability of operating under DRS is significantly larger than its impact on CRS, subject to a T-test.

Based on the above findings, we argue that the scope and scale of a reinsurer's operation need to be compatible with each other in order for the firm to be efficient. Our findings do not support Borch's (1962) prediction that full diversification is optimal for all types of reinsurers. We show, however, that significant cost scope diseconomies prevent small reinsurers from reaching full diversification.

4.4 Efficient Structure

Following Berry-Stoelzle et al. (2011), Choi and Weiss (2005), and Weiss and Choi (2008), we estimate reinsurers' price and underwriting profit based on the model in Equations (5a) and (5b). We measure the reinsurance unit price as the inverse of the smoothed loss ratio (for detailed discussions on defining insurance price, see Cummins & Danzon, 1997; Winter, 1994). The underwriting profit is defined as one minus the smoothed loss ratio minus the expense ratio (Choi & Weiss, 2005; Weiss & Choi, 2008). We use ROE to measure the overall profitability of a reinsurer. CE, SE, and XE approximate firm efficiency. Other independent variables include the market share of each firm in a given year, the reinsurance market growth rate per year, and the market concentration, measured by the market shares of the 10 largest reinsurers in respective years. X is a series of control variables, including leverage ratio, affiliation status, headquarter location dummies (market fixed effects). Different from Equation (1) and (4), year dummies are not included in Equation (5) due to the multicollinearity with market growth and market concentration.[23]

$$Price_{i,t} = \beta_0 + \beta_1 Efficiency_{i,t} + \beta_2 MarketShare_{i,t} + \beta_3 MarketConcentration_t + \beta_4 MarketGrowth_t + \beta_j X_{i,t} + \varepsilon_{i,t} \qquad (5a)$$

$$Profit_{i,t} = \beta_0 + \beta_1 Efficiency_{i,t} + \beta_2 MarketShare_{i,t} + \beta_3 MarketConcentration_t + \beta_4 MarketGrowth_t + \beta_j X_{i,t} + \varepsilon_{i,t} \qquad (5b)$$

Three alternative theories offer explanations for the market structure. A negative price efficiency correlation and a positive profit efficiency correlation support the ES hypothesis. Positive correlations between market share, price, and profit support the relative market power (RMP) hypothesis.[24] Positive correlations between market concentration, price, and profit support the structure-conduct-performance (SCP) hypothesis[25] (Choi & Weiss, 2005; Weiss & Choi, 2008).

[23] We examine multicollinearity by estimating VIFs of each independent variable in Equations (1) to (5). All values are below 5, suggesting that multicollinearity is not much of a problem.

[24] The RMP assumes that consumers rely on a firm's position in the market as an indicator of quality, thus predicting that larger firms have market power simply by virtue of their position in the market, which allows them to earn rents (Rhoades, 1985).

[25] The SCP suggests that market concentration may foster collusion among firms in the market. Higher concentration lowers the cost of collusion, resulting in monopoly rents (Weiss, 1974).

The results in Table 9 show that CE and its components (XE and SE) negatively correlate with price, positively correlate with underwriting profit, and have no significant impact on overall profitability. The results support Hypothesis 3 in the sense that cost-efficient reinsurers can charge lower prices without sacrificing profitability. The correlations between market share (market concentration) and both price and profit are insignificant, a finding which rejects the RMP (SCP) hypothesis.

Table 9
Test for efficient structure hypothesis

Variables	**Price**	**UW Profit**	**ROE**	**Price**	**UW Profit**	**ROE**
CE	-0.131***	7.508***	0.0550			
	(0.0229)	(2.105)	(0.0462)			
SE				-0.0764**	5.859**	-0.0565
				(0.0327)	(2.440)	(0.0376)
XE				-0.108***	5.777***	0.0816*
				(0.0230)	(1.986)	(0.0461)
Market share	0.00109	26.32	0.899	0.00301	26.27	0.839
	(0.437)	(32.58)	(0.665)	(0.432)	(32.17)	(0.655)
Market concentration	0.0569	0.175	-0.157	0.0700	-1.543	-0.0945
	(0.0888)	(7.762)	(0.102)	(0.0900)	(8.066)	(0.0894)
Market growth	0.000332	-0.0529	0.000834	0.000335	-0.0554*	0.000924
	(0.000230)	(0.0346)	(0.000637)	(0.000235)	(0.0335)	(0.000620)
Leverage ratio	-0.00849***	-0.373**	-0.0212	-0.00840***	-0.387**	-0.0210
	(0.00286)	(0.156)	(0.0198)	(0.00267)	(0.164)	(0.0196)
Unaffiliated	0.0146	-2.449	-0.00568	0.0135	-2.241	-0.0145
	(0.0311)	(2.774)	(0.0255)	(0.0317)	(2.781)	(0.0275)
Market FE/Constant	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	No	No	No	No
Overall R^2	0.314	0.057	0.051	0.315	0.065	0.054
Observations/number of reinsurers	841/116					

Notes: We present the results of random effects panel regressions with robust standard errors clustered at firm level provided in parentheses; *, **, *** denote the significant differences of the regression coefficients from 0 at the 10%, 5%, and 1% levels, respectively.

4.5 Robustness Tests

We conducted 12 tests to check the robustness of our conclusions. The results are documented in Supplementary Material C and are available from the authors upon request. All results are consistent with our conclusions, unless otherwise stated.

The first five robustness tests analyze alternative specifications of DEA first- and second-stage models. First, we use reinsurers' real net premiums written as an alternative output of the smoothed loss to represent the risk pooling function (Cummins & Weiss, 2013). Second, we consider alternative input prices, using (1) the MSCI yearly total return indices to replace the average realized ROE as the equity capital price and (2) the Producer Price Indices (PPI) to replace the CPI as the price for materials and business services. Third, as suggested by Simar and Wilson (2000), we use the double bootstrapping procedure in both the first- and the second-stage DEA analyses with 2,000 replications. Fourth, we consider two sets of alternative model specifications for DEA second-stage regressions: (1)

the truncated regression, proposed by Simar and Wilson (2007), and (2) the Tobit regression. Fifth, we use firm and year fixed effects models to replace the random effects models (with market and year dummies) for DEA second-stage regressions. Thus we omit time-invariant variables, for example, firm affiliation status and market fixed effects.

Robustness tests 6 to 9 are alternative analyses of Hypothesis 1. First, we take the top 10% scale-efficient firms in each year and then obtain the 25th and 75th percentiles of total assets in each year in robustness test 6. Similar to the firm-year pooled analyses in Table 4, we obtain an optimal asset range of USD 5.8 to 14.5 billion (inflation adjusted at 2012), which is slightly narrower than the optimal range obtained previously. Second, we separate our sample into two time periods, i.e., before the financial crisis (2002–2007) and after (2008–2012). The decile and vigintile analyses, similar to those in Table 4, suggest that there is no structural change regarding optimal size range before and after the financial crisis. Third, we separate our sample by region into mature markets (West Continental Europe, London, Bermuda, North America, and Asia Developed) and emerging markets (Africa, Asia Emerging, Eastern Europe, Latin America, and Middle East). The decile and vigintile analyses suggest that in emerging markets, the most cost-efficient reinsurers are concentrated in a smaller total asset range (between USD 4.3 and 7.6 billion) and that all reinsurers with total assets above USD 7.6 billion operate under DRS. Mature markets demonstrate a pattern similar to that of the global market (see Table 4). The superior management expertise and underwriting experience of reinsurers based in mature markets may enable them to manage large and globalized firms more efficiently, thus explaining the difference between emerging and mature markets. These analyses confirm the robustness of our optimal asset range of between USD 2.9 and 15.5 billion. Fourth, we use reinsurers' net premiums written to replace total assets as the size measure and test Hypothesis 1. The results suggest that there is an optimal size range between USD 0.91 to 3.65 billion in net premiums written (inflation adjusted at 2012). Our results are comparable to the optimal premium income range USD 2.3 to 4.9 billion found for multinational primary insurers (Katrishen & Scordis, 1998).[26] The analyses of efficiency determinants again confirm the inverse-U shaped size-SE relationship and the positive and linear size-CE relationship.

Regarding Hypothesis 3, we use the actual loss ratio to replace the smoothed loss ratio when calculating the reinsurance price and the underwriting profit ratio (robustness test 10). Since the actual loss ratio is very volatile in reinsurance, we only use values within the 5th and 95th percentiles in conducting the test. The results support the efficient structure hypothesis but not the alternative RMP and SCP hypotheses. In robustness test 11, a firm and year fixed effects model is employed to test

[26] Katrishen and Scordis (1998) focus on multinational primary insurers, apply a different empirical approach to identify economies of scale, and investigate a different sample period. The results thus are not fully comparable.

Hypothesis 3, in which we would have to omit all time invariant independent variables. Last, in robustness test 12, we use a subsample that includes only the observations without missing values. We do this because missing values for the number of employees were imputed for some data points in our core models. We generate a new set of DEA efficiency scores and re-perform all DEA second-stage regressions.

5. CONCLUSIONS

Our paper contributes to the international business and insurance literature by making four original conclusions. (1) Scale-efficient reinsurers exhibit an optimal size range between USD 2.9 and 15.5 billion in total assets, beyond which the scale economies are exhausted. These thresholds are larger than those found for the primary insurance market or other service industries. (2) The high cost-efficiency levels of large reinsurers are driven by their size. (3) A strategic focus strategy is appropriate for small reinsurers, whereas product diversification requires larger firm size. (4) Cost-efficient reinsurers can charge lower prices, while still achieve high underwriting profits. Our results provide new insights into the effects of economies of scale and scope on the global reinsurance market structure. The overall cost efficiency of large reinsurers explains their dominating position in the global market (Outreville, 2012b). The efficiency of small and specialized reinsurers and the absence of an impact of scope on medium and large reinsurers explain why both product-diversified and specialized firms appear to be competitively viable in the long run (Berger et al., 2000). These results are important not only for the reinsurance industry, but also for other financial services firms where complex interactions between scale, scope, and cost efficiency are present (for similar interactions in the banking market, see, e.g., Berger, Hanweck, & Humphrey, 1987).

Our findings have both macro policy and micro practice implications. Further consolidation is expected in the global reinsurance market, not only because it potentially improves cost efficiency, but also because it has the potential to lower reinsurance prices for consumers. Therefore, policymakers should be cautious about adopting anti-concentration measures in the global reinsurance market, as doing so may have the unintended consequence of raising the price of reinsurance and reducing industry cost efficiency. However, from the micro firm-level point of view, consolidation is not without its drawbacks, especially when considering limitations in economies of scale. Although scale diseconomies are offset by advantages in X-efficiency for the largest reinsurers, they become more problematic with further growth of those largest reinsurers. At this point, we cannot guarantee that technology and management progresses will adapt sufficiently fast enough to offset greater scale diseconomies in future consolidation. Thus, we do not argue for a natural monopoly in the global reinsurance market; rather, we suggest careful evaluation of the tradeoffs between scale diseconomies and potential gains in X-efficiency, especially for reinsurers already bigger than the optimal size range, when considering further merger and acquisition opportunities. Reinsurers should also be careful when evaluating conglomerate versus focused strategies. Specifically, small reinsurers need to be cautious about product diversification (i.e., adding life to nonlife business or vice versa) as doing so could significantly reduce cost efficiency.

The empirical research on global reinsurance markets is far from conclusive. Future research may provide more detailed guidance to reinsurers and policymakers as to, for example, which inputs (outputs) reinsurers can reduce (increase) to be more cost efficient. The impact of geographic and international diversification is also under-researched, due to data limitations. The inefficiencies of certain firms are not fully explained by firm-specific characteristics. The literature suggests that tax and/or other regulatory differences may play an important role in the presence of inefficiencies (Garven & Louberge, 1996), providing yet another fruitful direction for empirical investigation.

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