Journal of Banking and Finance 77 (2017) 213–229

Contents lists available at ScienceDirect

Journal of Banking and Finance

journal homepage: www.elsevier.com/locate/jbf

The structure of the global reinsurance market: An analysis of efficiency, scale, and scope

Christian Biener[a], Martin Eling[a,*], Ruo Jia[b]

[a] Institute of Insurance Economics, School of Finance, University of St. Gallen, Switzerland
[b] Department of Risk Management and Insurance, School of Economics, Peking University, China

ARTICLE INFO

Article history:
Received 13 December 2015
Accepted 18 January 2017
Available online 19 January 2017

JEL classification:
G22
L11
L25

Keywords:
Insurance
Cost efficiency
Market structure
Economies of scale
Economies of scope
Data envelopment analysis

ABSTRACT

We estimate economies of scale and scope as well as cost and revenue efficiency to explain the structure of the global reinsurance market, where large reinsurers dominate but both diversified and specialized reinsurers are competitive. The costs and benefits of size and product diversification are particularly relevant to the reinsurance industry, as risk diversification is central to the industry's business model. We find that reinsurers with total assets less than USD 2.9 billion exhibit scale economies, while those with total assets greater than USD 15.5 billion do not. Large reinsurers are characterized by high cost efficiency, while small reinsurers exhibit superior efficiency only when specialized. Large reinsurers also exhibit revenue scope economies when operating both life and nonlife reinsurance. Moreover, the evidence is in line with the efficient structure hypothesis: cost-efficient reinsurers can charge lower prices without sacrificing profitability.

© 2017 Elsevier B.V. All rights reserved.

1. Introduction

Reinsurers function as shock absorbers and risk bearers of last resort for the insurance industry and global economy. They provide services to primary insurers in terms of underwriting, pricing, claim management, and consultancy, enabling primary insurers to protect policyholders against risks, such as natural catastrophes, terrorism, and longevity. It has been shown that reinsurance also performs important strategic functions in insurance markets by supporting primary insurers to grow and to increase market share (Upreti and Adams, 2015). Moreover, reinsurers are a reliable source of alternative capital to primary insurers and to the global economy because of their large and long-term investment portfolios.

The reinsurance industry has undergone significant change in the 21st century, preceded by a number of large-scale catastrophes, the 2008 financial crisis, new competition from alternative risk transfer schemes, and new sources of capital from hedge funds and pension funds (Butt, 2007; Cummins and Weiss, 2009). These factors have resulted in consolidation (Cummins and Weiss, 2000; Cole and McCullough, 2006) 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 exist when more product diversified firms exhibit cost efficiency advantages relative to specialized firms (Clark, 1988; Elango et al., 2008; Panzar and Willig, 1977, 1981). Alternatively, Borch (1960, 1962) takes a different perspective and argues that the global reinsurance market should be structured around optimal risk allocation. He predicts that, in market equilibrium, all reinsurers hold a proportional share of the "market portfolio" that pools all risks. Borch's equilibrium implies the complete diversification of risks through a 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 product diversification[1] (scope), and thus provide

* Corresponding author at. Rosenbergstrasse 22, 9000 St. Gallen, Switzerland.
E-mail address: martin.eling@unisg.ch (M. Eling).

[1] This paper focuses on product diversification, an aspect not yet studied in the context of the global reinsurance market. Regarding geographical or international diversification in the reinsurance market, we refer to Cole, Lee, and McCullough (2007), Ma and Elango (2008), and Outreville (2012a). We also highlight poten-

http://dx.doi.org/10.1016/j.jbankfin.2017.01.017
0378-4266/© 2017 Elsevier B.V. All rights reserved.

a basis for analyzing their empirical validity and consequences for market structure. Reinsurance is a persuasive context to analyze market structure, not only because of the variety of recent corporate strategic changes (Klarner and Raisch, 2013), but also because of industry-specific features, such as the risk allocation problem (Borch, 1960, 1962), potentially motivating diversification. Moreover, its intangible and regulated nature may create entry barriers and limit options for diversification.

To date, academic research on reinsurance has focused on reinsurance demand, contract design, pricing, and reinsurance decisions (Bernard, 2013; Kader et al., 2010). However, the reinsurance market itself, especially the performance of reinsurers, has not received sufficient attention. Most literature on reinsurance performance applies traditional accounting indicators, such as return on equity (ROE), return on assets (ROA), or underwriting ratios (e.g., Chen and Hamwi, 2000; Cole et al., 2010; Cole and McCullough, 2008; Outreville, 2012a, 2012b). Cummins and Weiss (2000) provide the first piece of evidence on reinsurer efficiency regarding the tradeoff between the mean and standard deviation of ROE. Their approach is between the accounting performance measurement and the frontier efficiency performance measurement, because they include only one input and one output. In our view, the research gap in reinsurance can partially be attributed to the difficulty of consistently identifying reinsurers and combining datasets for a comprehensive picture of the global reinsurance market. Moreover, efficiency analysis in the financial services industry is challenging and has attracted less attention than the manufacturing industries for which output can be more clearly quantified.

This paper makes four contributions. First, we estimate reinsurer cost efficiency using data envelopment analysis (DEA) based on multiple inputs and outputs. Second, we analyze economies of scale and scope based on DEA frontier efficiency measures to explain the structure of the global reinsurance market. Third, we derive an optimal size range for reinsurers by uncovering thresholds at which scale economies are exhausted. Fourth, we test the efficient structure (ES) hypothesis in the global reinsurance market that predicts efficient firms to be more competitive due to their ability to charge lower prices without sacrificing profitability. To the best of our knowledge, none of these analyses has been conducted previously.

Our empirical results on scale efficiency suggest an optimal size range of reinsurers between USD 2.9 and 15.5 billion in total assets (inflation adjusted to 2012). Scale diseconomies of the largest reinsurers are offset by their strong X-efficiency, which is defined as the part of cost efficiency that cannot be explained by 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 (i.e., scope) decreases X-efficiency of small reinsurers. Our findings support the ES hypothesis in the sense that cost-efficient reinsurers can charge lower prices at comparable levels of profitability. Our results explain the current structure of the global reinsurance market, in which large reinsurers dominate but both diversified and specialized reinsurers persist.

Our research contributes to finance and insurance research by exposing the organization of the global market for risk transfer. The results illustrate the tradeoff between scale diseconomies and gains in X-efficiency, which is relevant for decisions about mergers and acquisitions and about firm growth in industries that are becoming more global. Hence, our work contributes to the ongoing discussion of the performance and efficiency of insurance companies (Eckles, et al., 2014), cross-country insurance operations (Pasiouras and Gaganis, 2013), and the systemic relevance of the reinsurance sector (Cummins and Weiss, 2014; Park and Xie, 2014).

This paper is organized as follows. In Section 2, we detail the theoretical foundation used to derive our hypotheses. In Section 3, we describe our data and methodology. In Section 4, we present the empirical results and check their robustness. Finally, we conclude and discuss future research topics in Section 5.

2. Hypothesis development

2.1. Economies of scale

The theory of economies of scale implies a potential optimal firm size and thus an optimal market structure. Scale economies (diseconomies) occur when a marginal proportional increase in the scale of inputs leads to a more (less) than proportional increase in outputs (Clark, 1988; Mansfield, 1970). Hence, competition is Pareto efficient if scale economies become exhausted at an output level 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 and Willig, 1977).

Economies of scale may exist in the reinsurance industry due to expensive IT systems, claim settlement operations, and risk management activities (Cummins and Xie, 2013), thus motivating market consolidation (Cummins et al., 1999; Cummins and Weiss, 2000; Lonkevich, 1995). However, large firm size can also lead to inefficiencies in the reinsurance industry due to agency problems, communication costs, and duplication efforts (Cummins and Weiss, 2013). Therefore, scale diseconomies may be present when the disadvantages of scale exceed the advantages. This tradeoff leads to our first hypothesis:

- *H1A: Reinsurer size has an inverse U-shaped relationship with scale efficiency.*

H1A implies that small reinsurers are more likely to operate under increasing returns to scale (IRS), medium-sized reinsurers are more likely to operate under constant returns to scale (CRS), and the largest reinsurers are more likely to operate under decreasing returns to scale (DRS). Similar relationships between firm size and scale efficiency are documented for many industries, for example, primary insurance (Bikker and Gorter, 2011; Cummins and Xie, 2013; Katrishen and Scordis, 1998) and banking (Berger and Humphrey, 1991; Noulas, Ray, and Miller, 1990). The presence of an inverse U-shaped relationship between reinsurer size and scale efficiency also implies an optimal size range, which we aim to identify.

2.2. Scale impact on cost efficiency

Cost efficiency contains aspects that cannot be explained by economies of scale (i.e., scale efficiency). To capture these aspects, we introduce the concept of X-efficiency (Berger, 1995; Cummins et al., 2010; Weiss and Choi, 2008),[2] defined as cost efficiency divided by scale efficiency, or pure technical efficiency multiplied by allocative efficiency. Therefore, we may observe the impact of

tial interactions between product and geographical diversification in Note 18 and in Section 5.

[2] The concept of X-efficiency was proposed by Leibenstein (1966) to capture all sources of unspecified inefficiencies that are not allocative efficiency. Berger (1995) follows the original intention of X-efficiency and defines it as the differences in costs that cannot be explained by differences in scale or other observable characteristics. Cummins et al. (2010) and Weiss and Choi (2008) go on to define X-efficiency for the insurance context; we follow their definition and employ X-efficiency as cost efficiency divided by scale efficiency or pure technical efficiency times allocative efficiency.

scale on cost efficiency via two channels, economies of scale (i.e., scale efficiency) and X-efficiency. The scale impact on X-efficiency is important to the reinsurance industry for two primary reasons. First, following the law of large numbers, large reinsurers exhibit lower loss volatility and, thus, are required to hold less equity capital, allowing them to manage more risks. Second, larger scale attracts qualified managers and experts to develop and maintain state-of-the-art technologies. Thus, large reinsurers potentially have stronger X-efficiency (Cummins and Weiss, 2000). We define our second hypothesis as follows:

- *H1B: Large reinsurers' strong X-efficiency offsets their scale diseconomies, resulting in an overall positive correlation between size and cost efficiency*.

2.3. Economies of scope

Panzar and Willig (1977, 1981) extend the concept of economies of scale to economies of scope. They suggest that firms become more cost efficient by extending their output from one to two or more products. The original concept of economies of scope concerns production costs, i.e., cost scope economies. Berger, Humphrey, and Pulley (1996) extend this concept to revenue scope economies in the banking industry, where they argue that consumers may be willing to pay more for one-stop shopping. We follow the original concept of cost scope economies in the main part of our paper, and investigate revenue scope economies as an additional test (see Section 4.6). 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 cost efficiency, any examination of market structure must also consider economies of scope.

Economies of scope are particularly important to the reinsurance industry because certain inputs, such as IT systems, policy services, and underwriting knowledge, can be used recurrently for multiple products, as in other industries (Teece, 1980), and because a more diversified product portfolio can reduce underwriting volatility (Cummins and Weiss, 2013), allowing for higher leverage and less equity capital (Lewellen, 1971). However, product diversification may also negatively influence efficiency. For example, more specialized firms may develop competencies in their core business, leading to decreased managerial and agency costs (Berger et al., 2000). Moreover, in the insurance context, life and nonlife insurance require different underwriting and pricing techniques, implying that the benefit from sharing underwriting knowledge may be negligible. Furthermore, reinsurers engaged in both primary and reinsurance business may be subject to conflicts of interest because their primary insurance line competes for primary insurance business with customers of their 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 and the strategic focus hypothesis. Berger et al., (2000) suggest that conglomeration is the dominant strategy for some types of insurers, such as larger insurers focusing on personal lines with a vertically integrated distribution system, whereas strategic focus is preferred by small insurers focusing on commercial lines with a nonintegrated distribution system. Therefore, it is important to examine whether the impact of product diversification (i.e., scope) varies by the type of reinsurer. Small reinsurers' distribution systems are typically not integrated (i.e., reinsurance brokers play an important role) and they are more likely to focus on commercial lines; we thus expect that strategic focus strategies prevail among small reinsurers. Following this line of reasoning, we define our third hypothesis as follows:

- *H2A: Specialization improves efficiency of small reinsurers*.

The distribution systems of large reinsurers are usually more integrated than those of small reinsurers as client manager teams handle large primary insurers to avoid the high brokerage costs of large transactions. Moreover, large insurers may have incentives to develop more lines of business to fully deploy their advanced and expensive IT systems. Large reinsurers also have larger management teams with various backgrounds and areas of expertise, thus enabling them to expand across different lines of business. Therefore, large reinsurers may reap additional benefits from economies of scope. Thus, we state our fourth hypothesis, the conglomeration hypothesis, as follows:

- *H2B: Product diversification improves efficiency of large reinsurers*.

2.4. Efficient structure

The ES hypothesis (Berger, 1995; Choi and Weiss, 2005; Weiss and Choi, 2008) explains the market structure from an efficiency perspective (Demsetz, 1973; Peltzman, 1977). More efficient firms have superior management, better production technology, or simply more efficient scale than other firms, and thus exhibit lower costs (Berger, 1995). Therefore, they can charge lower prices than inefficient firms while preserving profitability. Thus, we define our fifth hypothesis, the efficient structure hypothesis, as follows:

- *H3: Cost-efficient reinsurers can charge lower prices without sacrificing profitability*.

Market consolidation is an expected byproduct of efficiency differences, with more efficient reinsurers gaining market shares through consolidation (Choi and Weiss, 2005; Weiss and Choi, 2008). In other words, efficiency drives both profitability[3] (Greene and Segal, 2004; Leverty and Grace, 2010) and market structure (Berger, 1995) in the same direction. From a policymaker's perspective, such consolidation is beneficial for both firms (operating more efficiently) and customers (paying lower prices).

Choi and Weiss (2005) and Weiss and Choi (2008) develop an empirical framework to test the ES hypothesis in the context of the U.S. nonlife insurance market following Berger (1995). The ES hypothesis holds when a negative price-efficiency and a positive profit-efficiency correlation exist at the same time (Choi and Weiss, 2005; Weiss and Choi, 2008). They find that efficient insurers can charge lower prices and generate higher profits than inefficient insurers and, thus, achieve higher market share. Additionally, Berry-Stölzle, Weiss, and Wende (2011) support the ES hypothesis in the European nonlife insurance market.

Two alternative theories offer explanations for the market structure. The relative market power (RMP) hypothesis 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). The RMP hypothesis expects positive correlations between market share, price, and profit. The structure-conduct-performance (SCP) hypothesis 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 SCP hypothesis expects positive correlations between market concentration, price, and profit. We test both the RMP and the SCP hypothesis.

[3] An important question in frontier efficiency studies is how the efficiency measure is related to the conventional measures of firm profitability (Greene and Segal, 2004; Leverty and Grace, 2010). We observe, as a corollary of ES hypothesis tests, a significant and positive correlation between cost efficiency and a firm's underwriting profit, but a weaker positive correlation between cost efficiency and a firm's returns on equity. This finding is generally consistent with the findings for the U.S. life insurance industry (Greene and Segal, 2004) and for the U.S. nonlife insurance industry (Leverty and Grace, 2010).

The scale impact on cost efficiency (H1B) and the ES hypothesis (H3) are potentially interconnected for the following three consecutive reasons. Large firm size yields high cost efficiency; cost-efficient firms can charge lower prices without sacrificing profitability and, thus, attract more clients than inefficient firms; and, cost-efficient firms will increase in size by either organic growth or acquiring less efficient firms. We apply a Granger test to verify this potential connection.

In summary, our hypotheses 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 comprise large (diversified) firms; alternatively, if technology does not allow such economies, small (specialized) firms will tend to dominate (Clark, 1988). The existence of scale and scope economies as well as competitive pricing advantages of cost-efficient firms indicate the potential for market consolidation from a production perspective.

3. Data and methodology

3.1. Sample construction and representativeness

A persistent challenge for reinsurance research is the identification of a single coherent data source containing all information necessary to conduct a global efficiency study (Cummins and Weiss, 2000). We leverage the following four sources to construct a global and comprehensive sample of reinsurers: Best's Insurance Reports (A.M. Best, 2002–2012), which include general and financial information of all non-U.S. reinsurers; Standard & Poor's Global Reinsurance Highlights (Standard & Poor's Rating Services, 2003–2013), which include a global reinsurance survey for each year and contain the most complete list of active reinsurers worldwide; annual reports of reinsurers (2002–2012), which are our major source for the number of employees and financial information of U.S. reinsurers; and Best's Special Report on Global Reinsurance (A.M. Best, 2013), from which we use the list of the top 50 reinsurers to complete missing values.

The global reinsurance market is dominated by professional reinsurers (Holzheu and Lechner, 2007). A professional reinsurer is a firm for which open market reinsurance is the major business. Primary insurers may also engage in reinsurance business as a sideline. Different approaches are used to empirically differentiate professional reinsurers from primary insurers (Beaver et al., 2003; Cole and McCullough, 2006; Cummins and Weiss, 2000). Cole and McCullough (2008) find that the criteria used to identify reinsurers significantly influence empirical outcomes, a standard empirical selection bias problem. They also show that efforts to unify the definition of a reinsurer are rather inconclusive. Whether a company is a reinsurer or a primary insurer is much more ambiguous than whether a company is a life or a nonlife insurer. This is because some insurers sell both primary insurance and reinsurance, and because reinsurance often covers a significant share of transactions between affiliated firms (e.g., subsidiaries reinsure their portfolios with their headquarters). In this paper, we do not aim to solve the reinsurance definition problem, but instead we rely on a comprehensive sample of reinsurers covering the majority of the global reinsurance market, thus limiting selection issues.

We follow a four-step algorithm to generate our sample of professional reinsurers. First, a firm's reinsurance premiums written must account for more than 50% of its total premiums written (Beaver et al., 2003). Second, we identify one entity within one reinsurance group that best captures the reinsurance business of the group. We focus on the reinsurance business share, that is the reinsurance premium of the entity selected to that of the whole reinsurance group,[4] setting a threshold of 50%. Only those entities above the threshold are considered as representative of the reinsurance group. Third, if multiple entities record more than 50% of the reinsurance business of the group, we select the one that is the A.M. Best Rating Unit, which identifies the entity best representing the reinsurance group's operation 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.[5]

We employ data from 2012 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 other reinsurers in our sample, instead of going bankrupt.[6] The poor performance of acquired reinsurers is internalized by the acquiring reinsurers. A potential survivorship bias should thus be minimal. Another problematic aspect might be that our dataset is at the firm-year level, and thus we are not able to allocate firm-specific resources (e.g., firm assets) to the reinsurance and primary business separately if the reinsurer operates both. However, this problem is mitigated by our reinsurer selection process, where we ensure that the major business of the reinsurer is reinsurance and we select the operating entity that best captures the firm's reinsurance business.

We considered whether multiple units of one reinsurance group or one group-level consolidated unit should be used for the efficiency analyses, and opted for the latter approach for the following reasons. First, from an input perspective, many headquarter employees provide services to all regions irrespective of their legal entity, and many employees in the regional entities have both group and regional functions.[7] Second, from an output perspective, premiums and losses are not necessarily booked under the entity that underwrites the risk. Both premiums and losses may be transferred within a group by internal reinsurance transactions. Thus, if we consider multiple units, the input volume might not correspond to the output volume. Third, from a dataset perspective, the consolidated unit has the most complete and accurate information, also because it is usually used as the rating unit by A.M. Best. Information about subsidiaries is sometimes not publicly disclosed, is of different quality (i.e., have more missing values), and may exhibit different accounting standards, making it more difficult to compare.

Our final sample contains 116 professional reinsurers and 841 firm-years.[8] The total net reinsurance premiums written by our

[4] In steps 1 and 2, we consider gross premiums; if these are not available, we use net premiums.

[5] 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 is reinsurance, and, thus, they do not meet the criteria of a professional reinsurer. Captives, reinsurance pools, and "bridge reinsurers" have operating models different from traditional reinsurers, and their financial results are not fully comparable to traditional reinsurers. Thus, we do not include them in our analysis.

[6] We identified 14 cases where 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. For example, 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 the purpose of risk diversification.

[7] For example, Swiss Re centralizes most of its risk engineering and some underwriting services in the Swiss headquarter and employees working in these fields provide services globally. Although there is internal cost allocation, these services are not fully captured by the labor input (the actual number of employees) if multiple units are considered.

[8] Some values are missing from our dataset due to the unavailability of some inputs and outputs from our four data sources. The most common missing values

Table 1
Sample representativeness.

	Net reinsurance premiums written in 2012 (in billion USD)		% captured by sample
	Selected unit (used in this paper)	Group total (taken from Global Reinsurance Highlights, 2013)	
Munich Re	35.8	35.8	100
Swiss Re	21.3	25.3	85
Hannover Re	16.3	16.3	100
Scor Re	11.3	11.3	100
Total reinsurance market	163.9	179.2	91

Notes: we do not capture 100% group net reinsurance premiums written for Swiss Re because Swiss Re group includes a segment of run-off business (Admin Re) and a segment of primary insurance business (Corporate Solutions). Global Reinsurance Highlights (2013) considers all of these businesses as reinsurance. Bearing in mind the purpose of analyzing the global reinsurance market structure and to be consistent with our sample construction procedure in Section 3.1, we use the Swiss Reinsurance Company Limited entity (i.e., the core reinsurance business entity), which is reported separately in the Swiss Re group reports. Other large reinsurance groups, e.g., Munich Re, also have primary insurance businesses, which, however, are not included in the group total net reinsurance premiums of the Global Reinsurance Highlights (2013).

sample in 2012 is USD 164 billion, representing 91% of the professional reinsurance market and 71% of the total global reinsurance market.[9] The reinsurance business in our sample varies from treaty to facultative reinsurance and from proportional to non-proportional reinsurance; however, detailed information regarding the 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) for the operating expense ratio and business services ratio.[10] These reinsurers with extreme values are mostly startups that do not yet underwrite reinsurance, runoff reinsurers, or reinsurers operating under an extreme outsourcing model. Thus, they are not comparable to or in competition with regular reinsurers.

We critically reflect our sample construction procedure by comparing the reinsurance premium captured in our sample with the group total reinsurance premium for the Big 4 reinsurance groups in 2012 (Munich Re, Swiss Re, Hannover Re, and Scor Re account for around 50% of the global reinsurance premium; see Standard & Poor's Rating Services, 2013). The results in Table 1 illustrate that our sample construction procedure captures most reinsurance activities of the large reinsurance groups.

3.2. Summary statistics

Table 2 presents the sample summary statistics. In Appendix A we present further statistics on the geographical and yearly distribution. Of the professional reinsurers, 45% engage in both life and nonlife reinsurance; 16% write significant amounts of primary insurance, having a reinsurance premium share between 50% and 95%; and 25% operate as unaffiliated single firms; and, the remaining firms operate as groups or affiliates with others. The average leverage ratio (liability to equity) is 2.75, which is slightly higher than the leverage ratio of 2.13 documented by Cummins and Weiss (2000).

A study of the reinsurance market must be conducted at a global (i.e., cross-country) level because reinsurance risks are shared across borders, resulting in global business portfolios. Even national reinsurers (e.g., China Re) assume significant portions of European, American, and South East Asian exposures and cede substantial portions of Chinese exposures through retrocessions. Therefore, we assume that reinsurers operate in a global market and estimate a one-world frontier in subsequent DEA estimations. Global reinsurers, nevertheless, are heterogeneous in size, headquarter location, product specialization, and underwriting risk (Pasiouras and Gaganis, 2013). Hence, it is important to manage potential heterogeneity by including market (or firm) fixed effects throughout the analyses.

3.3. Data envelopment analysis

We use input-oriented data envelopment analysis (DEA), assuming constant returns to scale (CRS), variable returns to scale (VRS), and non-increasing returns to scale (NIRS) to estimate efficient production frontiers separately for each year between 2002 and 2012 (Cook and Zhu, 2014; Cummins and Weiss, 2013), an empirical approach frequently employed in finance and insurance research (Leverty and Grace, 2010; Curi et al., 2015). We compute Farrell's (1957) input efficiency, which are the reciprocals of the respective Shephard (1970) measures. The resulting measures of cost efficiency (CE), allocative efficiency (AE), pure technical efficiency (PTE), and scale efficiency (SE) represent the firm's distance from the respective best-practice efficient frontiers, and are bounded between 0 and 1. Moreover, we estimate X-efficiency (XE), defined as CE divided by SE or as the product of PTE and AE (Cummins et al., 2010; Weiss and Choi, 2008). Finally, we estimate revenue efficiency (RE) scores in order to analyze revenue scope economies (see Section 4.6). Table 3 summarizes definitions of the DEA terms.

We exploit the variation of efficiency estimates for the different production frontiers of a reinsurance firm to make inferences about scale economies (Aly et al., 1990), that is, to discover whether a firm operates under IRS or DRS if it is scale inefficient.[11] By definition, the scale efficient firms operate under CRS. Simar and Wilson (2000) suggest a bootstrapping bias-correction procedure for DEA analysis. This approach, however, leads to a bootstrapping bias, which differs for CRS, VRS, and NIRS frontiers. Thus, the results

are the number of employees. We fill in the missing information using predicted values that we imputed based on observed information. For example, we use operating expenses to impute the number of employees. In Section 4.6, we conduct a robustness test using only the original data and excluding observations containing missing values. The results are consistent with our conclusions.

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

[10] The operating expense ratio is defined as the operating expenses divided by the net premiums written. The business services ratio is defined as the cost of materials and business services divided by the total operating expenses. This trimming procedure excludes 4% firm-year observations from our sample. The business service ratio captures the tradeoff between using employees and using independent contractors.

[11] According to Aly et al. (1990), if a firm's technical efficiency against the VRS frontier is smaller than that against the NIRS frontier, then it operates under IRS; if a firm is scale inefficient and its technical efficiency against the VRS frontier equals that against the NIRS frontier, then it operates under DRS.

Table 2
Summary statistics.

	Unit	Mean	Std. dev.	Min.	10th percentile	50th percentile	90th percentile	Max.
Panel A: Input quantities								
Number of employees	1	538.5	1,572.5	2[h]	38	122	1,038	11,702
Quantity of materials and business services	1,000	539,129	2,008,515	167	7,838	94,785	707,956	19,888,900
Equity capital and surplus [a]	1,000	1,919,850	4,845,149	627	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	100.0	101.3
PPI with base year of 2012 [b]	%	87.4	13.2	32.2	70.7	91.2	100.0	112.8
ROE of the reinsurance industry	1	0.096	0.037	0.041	0.047	0.10	0.13	0.16
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	71,407	844,445	11,022,524	277,719,424
Smoothed loss [a]	1,000	1,467,686	5,055,169	731	17,791	241,395	2,351,311	43,623,480
Net premiums written [a]	1,000	2,110,135	7,197,933	946	27,166	369,349	3,613,961	66,319,992
Panel D: Others								
Total assets [a]	1,000	11,581,832	44,005,533	2,150	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 [g]	%	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 (1-smoothed loss ratio)	%	3.44	11.1	-59.1	-7.23	3.92	15.6	40.0
Market growth	%	6.82	8.40	-8.10	-2.90	7.30	14.4	33.1
Price of reinsurance (inverse of smoothed loss ratio-1)	1	0.53	0.16	0.033	0.34	0.52	0.75	1.25
Number of firm-year observations (firms)	841 (116)							

Notes:
[a] In USD and inflation adjusted to 2012.
[b] For the following countries, PPIs are not available and thus replaced by CPIs: Barbados, Bermuda, Cayman Islands, Dominican Republic, Ghana, Kenya, Lebanon, and Nigeria.
[c] Information is only available for the year 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 and 0 otherwise.
[e] Conglomerate equals 1 if the primary insurance premium takes more than 5% and less than 50% of the total premium written and 0 otherwise.
[f] Unaffiliated equals 1 if the reinsurer is an unaffiliated single firm and 0 otherwise.
[g] The smoothed loss ratios are calculated based on the actual loss ratios following the procedure in Cummins and Xie (2008), described in Appendix B.
[h] The small minimum number of employees is a result of the estimated employee number (see Note 8), where the actual number of employees is missing.

Table 3
DEA efficiency terms.

Term	Abbreviation	Description	Decomposition
Pure Technical Efficiency	PTE	Technical efficiency on various returns to scale, capturing the relative production technology the firm employs (i.e., the part of technical efficiency that cannot be explained by scale efficiency)	
Allocative Efficiency	AE	Efficiency in allocating resources among different inputs	
Scale Efficiency	SE	Equals 1 if constant returns to scale, less than 1 if various (increasing or decreasing) returns to scale	
Cost Efficiency	CE	Minimum (i.e., optimal) costs to observed (i.e., actual) costs	CE=SE×PTE×AE or CE=SE×XE
X-Efficiency	XE	The part of cost efficiency that cannot be explained by scale efficiency	XE=CE÷SE or XE=PTE×AE
Revenue Efficiency	RE	Observed (i.e., actual) revenues to maximum (i.e., optimal) revenues	

cannot be easily used to make inferences about returns to scale. Consequently, we present the original efficiency estimates without bias-correction throughout the paper and show the results subject to the bootstrapping bias-correction procedure as a robustness test.

Compared to accounting performance measures (e.g., ROE, ROA), the advantage of DEA is that the resulting cost efficiency measure can be decomposed into several components, illustrating the process through which scale and scope affect cost efficiency. This is particularly useful in analyzing market structure. The relative benchmarking concept of DEA is informative and important, as managers measure their performance against industry best practices. Moreover, DEA decomposition informs management of the direction or component to improve (i.e., scale, technology, or resource allocation).[12]

[12] The DEA frontier efficiency measures have limitations that restrict their application in practice. For example, the benchmark best practices change with the development of the industry in each year. While the dynamic nature captures the full changes in a firm, it may not meet the static requirement of regulations.

For DEA input quantities, we use labor (i.e., number of employees), materials and business services,[13] and total equity capital in real values as of 2012, following common practice in insurance DEA studies (Cummins and Weiss, 2013). The number of employees is hand-collected from annual reports of the respective reinsurers. We use annual average wages for the insurance sector (banking, if insurance is not available) in respective country-years as the price-proxy for labor. Wage information is obtained from the ILO Main Statistics and October Inquiry databases.[14] The total employee costs are therefore equal to the product of the number of employees and annual average wage in the respective countries. The quantity of materials and business 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 prices indices (CPIs) of respective country-years. We approximate total equity capital by the capital and surplus in Best's Insurance Reports (A.M. Best, 2002–2012). We use the overall ROE of the reinsurance industry in each year as the price of equity capital. An alternative proxy would be to use stock indices. We choose the total industry return in the main part of the paper since it more closely reflects the expected capital returns of the reinsurance industry, whereas the stock indices reflect the price of capital across all industries.[15]

For DEA output quantities, we use smoothed losses and total invested assets (both in real values as of 2012). These represent two major functions of a reinsurer: risk pooling (i.e., risk bearing) and financial intermediation. Reinsurers also serve as think tanks and consultants to primary insurers; however, they do not usually charge for such services, but use them to acquire new business. Therefore, the consulting function is integrated into, and reflected by, the loss output. Loss reflects the quantity of risk that the reinsurer pools and redistributes. More losses indicate more risk assumed. Thus, loss measurements are widely used in insurance DEA studies as an output (Cummins and Weiss, 2013). We calculate smoothed losses based on the loss-smoothing procedure in Cummins and Xie (2008), described in Appendix B. This procedure is particularly well-suited for the highly volatile losses of reinsurance because it corrects the potential "error in variables" problem due to the random nature of losses (Cummins and Xie, 2013). We approximate total invested assets by total investments from Best's Insurance Reports (A.M. Best, 2002–2012). To estimate revenue efficiency (see Section 4.6), we use the inverse of the smoothed loss ratio minus one as the price for the risk pooling function (Cummins and Danzon, 1997; Winter, 1994).[16] We then use the annual realized industry-wide investment returns – an approximation of expected investment returns – as the price for the financial intermediation function (Cummins and Weiss, 2013).

[13] Materials and business services are usually combined together in insurance DEA studies to represent the remaining part of the insurer's operating expenses other than employee expenses. It includes items such as travel, communications, and advertising (Eling and Luhnen, 2010), and is usually not further subdivided due to data limitations. There is a tradeoff between using employees and outsourcing functions. A part of the materials and business services capture outsourcing expenses, and the input of labor captures the employee expenses. We thus expect the tradeoff has no significant influence on our DEA results.

[14] Wage data are 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.

[15] In Section 4.6 we perform and discuss robustness checks with alternative input, output, and price measures, the results of which are consistent with our conclusions.

[16] A higher reinsurance premium indicates a larger loading on top of the same risk pooling services. The inverse of the smoothed loss ratio minus one thus captures the "loading" of risk pooling services.

After deriving the DEA efficiency scores, we perform DEA second stage regressions[17] as follows (Cooper et al., 2011):

$$\begin{aligned} Efficiency_{i,t} = {} & \beta_0 + \beta_1 Scale_{i,t} + \beta_2 Scale_{i,t}{}^2 \\ & + \beta_3 Scope_i + \beta_j X_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (1)$$

Following our hypotheses, we define efficiency as a function of firm scale, scope, and a series of firm-specific and country-specific control variables. Our hypotheses include a nonlinearity assumption for the relationship between firm size and some efficiency measures. Therefore, we use the natural logarithm of real total assets (*lnAsset*) and its squared term to capture this nonlinear size effect. Each *lnAsset* is centered at the mean of all firm-year *lnAsset* values to avoid multicollinearity between size and its squared term. The centered *lnAsset* is defined as follows: $lnAsset_{centered\,i,t} = lnAsset_{i,t} - \overline{lnAsset}$, where $\overline{lnAsset}$ is the average of all firm-years. All total assets values are inflation adjusted to 2012. We capture the scope of a reinsurer by two dummy variables: *composite* measures a reinsurer's product diversification across life and nonlife reinsurance; *conglomerate* measures a reinsurer's product diversification across reinsurance and primary insurance.

The vector X represents a series of control variables, including leverage ratio (i.e., total liabilities divided by total equity and surplus), affiliation status (1 if the reinsurer is an unaffiliated single firm, 0 otherwise), headquarter location dummies (i.e., market fixed effects), and year dummies (i.e., time fixed effects). 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 and Lechner, 2007). The additional regional markets include Asia Developed, Asia Emerging, Africa, Eastern Europe, Latin America, and the Middle East. The regressions incorporate the year fixed effects and, thus, control for the differences resulting from the yearly frontiers. After controlling for the market and year fixed effects, we estimate Eq. (1) with random effects panel regressions suggested by Hausman and log-likelihood ratio tests. We also conduct robustness tests with alternative estimation techniques, the results of which are consistent with our conclusions (see Section 4.6).

4. Empirical results

4.1. Efficiency estimations

Table 4 reports average efficiency scores by year and size. For each year, we estimate three size quantiles based on total assets (Biener et al., 2015; Luhnen, 2009). Small reinsurers are significantly less SE than medium and large reinsurers. For PTE, small and large reinsurers are in most cases more efficient than medium reinsurers. For AE, there are no observable significant differences between the size categories in most years. XE exhibits similar patterns as PTE where small reinsurers are more (less) X-efficient than medium (large) reinsurers in most years. CE increases with firm size in all years except in 2002, indicating preliminary support for H1B. Similar to the CE pattern, RE also increases with firm size in most years.

4.2. Economies of scale

By definition, firms exhibiting a SE score of 1 operate under CRS. For scale-inefficient firms, we follow Aly et al., (1990) to de-

[17] There is a debate regarding whether DEA second stage regressions are appropriate. One of the concerns is that the factors used to derive the efficiency scores should not appear again as the explanatory variable in the second stage regressions. We comply with this requirement. We refer to Cooper, Seiford, and Zhu (2011) for the detailed discussion regarding the DEA second stage regression.

Table 4
DEA efficiency results.

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	All	E=1[b]
Observations	46	52	50	50	80	81	81	97	105	101	98	841	
Panel A: SE													
All	0.867	0.920	0.946	0.709	0.652	0.789	0.841	0.876	0.763	0.873	0.885	0.826	95
Small	0.712	0.851	0.871	0.438	0.389	0.544	0.660	0.755	0.567	0.693	0.747	0.651	14
Medium	0.954	0.976	0.984	0.812	0.689	0.848	0.904	0.958	0.861	0.950	0.964	0.898	24
Large	0.946	0.938	0.984	0.888	0.888	0.975	0.960	0.917	0.863	0.978	0.944	0.933	57
P-value [a]	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Panel B: PTE													
All	0.740	0.685	0.722	0.631	0.560	0.656	0.625	0.658	0.533	0.702	0.693	0.648	157
Small	0.666	0.550	0.646	0.698	0.692	0.626	0.638	0.680	0.610	0.708	0.703	0.659	44
Medium	0.781	0.736	0.723	0.509	0.420	0.569	0.529	0.595	0.438	0.613	0.644	0.579	29
Large	0.778	0.778	0.803	0.691	0.570	0.773	0.710	0.700	0.553	0.789	0.734	0.706	84
P-value [a]	0.215	0.010	0.073	0.056	0.000	0.002	0.012	0.125	0.013	0.004	0.203	0.000	
Panel C: AE													
All	0.836	0.801	0.872	0.786	0.663	0.652	0.527	0.802	0.620	0.565	0.846	0.708	22
Small	0.872	0.855	0.904	0.800	0.626	0.738	0.546	0.778	0.566	0.536	0.827	0.707	2
Medium	0.806	0.745	0.810	0.756	0.696	0.588	0.530	0.812	0.634	0.514	0.863	0.692	4
Large	0.829	0.801	0.903	0.803	0.666	0.631	0.505	0.817	0.660	0.646	0.848	0.721	16
P-value [a]	0.455	0.111	0.033	0.614	0.490	0.007	0.678	0.594	0.139	0.014	0.662	0.275	
Panel D: XE													
All	0.610	0.535	0.624	0.482	0.344	0.413	0.315	0.512	0.301	0.389	0.570	0.445	22
Small	0.569	0.470	0.580	0.541	0.407	0.447	0.326	0.501	0.326	0.367	0.562	0.449	2
Medium	0.631	0.532	0.575	0.366	0.262	0.313	0.268	0.475	0.247	0.301	0.537	0.388	4
Large	0.632	0.607	0.722	0.544	0.366	0.480	0.352	0.561	0.332	0.502	0.614	0.499	16
P-value [a]	0.553	0.137	0.026	0.008	0.006	0.000	0.087	0.143	0.018	0.001	0.197	0.000	
Panel E: CE													
All	0.530	0.490	0.592	0.331	0.209	0.321	0.260	0.446	0.218	0.341	0.503	0.368	22
Small	0.391	0.391	0.503	0.217	0.141	0.229	0.200	0.372	0.169	0.250	0.415	0.286	2
Medium	0.608	0.519	0.568	0.306	0.178	0.267	0.241	0.457	0.212	0.285	0.519	0.356	4
Large	0.599	0.564	0.711	0.479	0.313	0.468	0.339	0.511	0.273	0.493	0.577	0.464	16
P-value [a]	0.003	0.025	0.004	0.000	0.000	0.000	0.001	0.003	0.000	0.000	0.001	0.000	
Panel F: RE													
All	0.584	0.588	0.635	0.182	0.225	0.465	0.492	0.513	0.329	0.479	0.565	0.454	54
Small	0.379	0.401	0.508	0.134	0.176	0.273	0.387	0.465	0.280	0.382	0.488	0.356	5
Medium	0.685	0.676	0.649	0.167	0.214	0.459	0.446	0.504	0.326	0.510	0.573	0.461	16
Large	0.703	0.697	0.754	0.249	0.286	0.664	0.643	0.572	0.380	0.546	0.637	0.548	33
P-value [a]	0.000	0.000	0.003	0.123	0.026	0.000	0.000	0.125	0.102	0.005	0.007	0.000	

Notes: we present arithmetic means of the respective efficiency scores in respective size categories and years.
[a] We perform mean difference F-tests to examine whether the average efficiency scores in different size categories are equal to each other.
[b] This column shows the number of efficient firm-years (i.e., efficiency score equals to 1).

termine whether those operate under IRS or DRS. The results in Columns (1) to (6) of Table 5 show that 68% of all reinsurers operate under IRS, 11% under CRS, and 21% under DRS. Large reinsurers are more likely to exhibit CRS and DRS, and small reinsurers comprise a higher proportion of the IRS firms.

We follow Cummins and Zi (1998) and Cummins and Xie (2013) to identify firm size thresholds at which scale economies are exhausted and split the firm-year observations into deciles (Panel A) and vigintiles (Panel B). Of the reinsurers with total assets below USD 4.3 billion, more than 74% operate under IRS. None of the reinsurers with total assets above USD 15.5 billion operate under IRS, 71% operate under DRS. This finding supports H1A in the sense that small reinsurers are more likely to operate under IRS and that the largest reinsurers are more likely to operate under DRS.

The mean SE scores (Column (7) of Table 5) show one significant jump from the 15th vigintile (2.04B-2.90B) to the 16th vigintile (2.90B-4.30B), and one significant drop from the 9th decile (7.60B-15.50B) to the 10th decile (> 15.50B). These results suggest an optimal size range with significantly higher scale efficiency scores between USD 2.9 and 15.5 billion, again supporting H1A. The range of USD 12.6 billion (2.9–15.5 billion) seems wide; however, it represents only 28.6% of one standard deviation of our sample reinsurers' total assets (i.e., USD 44.0 billions). Thus it is a relatively accurate range considering the entire size spectrum.

Comparing our results with the primary insurance industry, the size at which reinsurers' scale economies are exhausted is much larger than that of life insurers (USD 1 billion; Cummins and Zi, 1998) and nonlife insurers (USD 137.1 million; Cummins and Xie, 2013). These differences might be explained by the global nature of the reinsurance business.

We apply a DEA second-stage regression to the SE scores, as defined in Eq. (1). The results in Column (1) of Table 6 show that SE increases with firm size at a decreasing rate, then reaches optimal size, and subsequently decreases with firm size, as indicated by the positive sign of the linear term and the negative sign of the quadratic term for *lnAsset*, which is in line with H1A.

Similar to Berger and Humphrey (1991) and McAllister and McManus (1993), we visualize the optimal asset range by predicting SE scores from the regression and extracting the top 10% scale-efficient firm-year observations in Fig. 1. The two vertical lines mark the USD 2.9 to 15.5 billion optimal size range identified by

Table 5
Returns to scale and efficiency results by firm size.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Firm-yea	Relative share (in%)		Relative share (in%)			Mean of SE	Std. dev. of SE	Firm-years	Firms
Total assets	IRS	CRS	DRS	IRS	CRS	DRS				
Panel A: Size deciles										
< 97 M	81	4	0	95	5	0	0.545 (N.A.)	0.237	85	17
97M–237M	78	3	3	93	4	4	0.679***	0.228	84	22
237M–435M	75	5	4	89	6	5	0.682	0.207	84	29
435M–795M	79	4	1	94	5	1	0.809***	0.174	84	28
795M–1.28B	79	4	1	94	5	1	0.897***	0.124	84	28
1.28B–2.04B	66	11	7	79	13	8	0.911	0.114	84	25
2.04B–4.30B	62	10	12	74	12	14	0.951***	0.062	84	23
4.30B–7.60B	32	16	36	38	19	43	0.966*	0.046	84	22
7.60B–15.5B	20	14	50	24	17	60	0.963	0.051	84	17
> 15.5B	0	24	60	0	29	71	0.858***	0.151	84	12
Panel B: Size vigintiles										
<57M	41	2	0	95	5	0	0.548 (N.A.)	0.229	43	10
57M-97M	40	2	0	95	5	0	0.542	0.247	42	12
97M-163M	38	1	3	90	2	7	0.716**	0.228	42	14
163M-237M	40	2	0	95	5	0	0.643	0.225	42	16
237M-314M	38	3	1	90	7	2	0.629	0.222	42	20
314M-435M	37	2	3	88	5	7	0.736**	0.178	42	19
435M-580M	39	2	1	93	5	2	0.782	0.180	42	18
580M-795M	40	2	0	95	5	0	0.836	0.164	42	21
795M-1.02B	38	4	0	90	10	0	0.887	0.139	42	22
1.02B-1.28B	41	0	1	98	0	2	0.906	0.109	42	18
1.28B-1.51B	34	6	2	81	14	5	0.905	0.128	42	20
1.51B-2.04B	32	5	5	76	12	12	0.918	0.100	42	20
2.04B–2.90B	31	6	5	74	14	12	0.940	0.067	42	18
2.90B–4.30B	31	4	7	74	10	16	0.963*	0.056	42	15
4.30B-5.80B	14	9	19	33	21	45	0.958	0.054	42	17
5.80B-7.60B	18	7	17	43	17	40	0.975	0.036	42	17
7.60B-10.5B	11	4	27	26	10	64	0.964	0.050	42	13
10.5B-15.5B	9	10	23	21	24	55	0.963	0.053	42	13
15.5B-35.1B	0	7	35	0	17	83	0.841***	0.156	42	8
>35.1B	0	17	25	0	40	60	0.875	0.146	42	7
Total	572	95	174	68	11	21	0.826	0.207	841	116 [a]

Notes: *, **, *** represent statistical significance at the 10%, 5% and 1% level, respectively, for the mean difference *t*-tests between two consecutive size categories (i.e., between the size category of interest and its preceding smaller size category). The first SE mean is not preceded by a smaller category and thus marked as N.A.

[a] The total number of firms does not equal the sum of the firms in each sub-category because one firm could belong to different categories in different years.

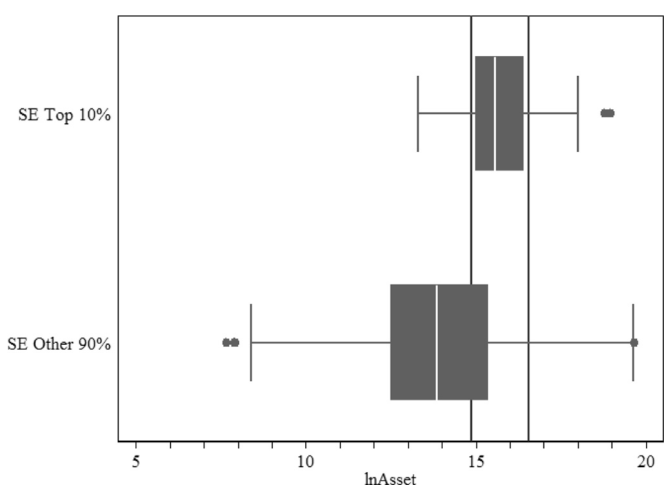

Fig 1. Optimal size range.
The box plots show the distribution of *lnAsset* for the predicted top 10% scale-efficient firm-years and the 90% non-scale-efficient firm-years. The two vertical lines indicate the optimal size range (USD 2.9 to 15.5 billion) identified by the decile and vigintile analyses.

the decile and vigintile analyses. The box plots show that for the top 10% scale-efficient observations, total assets within the 25th and 75th percentiles are in the area between the two vertical lines (i.e., within the optimal size range). Around 60% of the top 10% scale-efficient observations have total assets ranging within the identified optimal size range.

4.3. Scale impact on cost efficiency

To assess the scale impact on the overall cost efficiency and its components, we estimate Eq. (1) with PTE, AE, XE, and CE scores (Columns (2) to (5) of Table 6), respectively. The results in Column (5) confirm H1B by showing that the reinsurers' CE scores increase with firm size. The PTE results in Column (2) suggest a U-shaped relationship between firm size and PTE. Both small and large reinsurers are more likely to employ state-of-the-art technologies than medium-sized reinsurers. The results in Column (3) suggest a positive linear relationship between firm size and AE. The XE results in Columns (4) show the combined effects of PTE and AE.

Large reinsurers are indeed most cost efficient because they define the best-practice technology frontier and best allocate their costs among different inputs. Their advantages in XE (indicated by the positive coefficient of *lnAsset* and $lnAsset^2$) offsets the extant scale inefficiencies (i.e., scale diseconomies). Small reinsurers are also able to exploit best-practice technologies; the superior PTE of some small reinsurers may result from their expertise in special segments (i.e., a focused strategy). We test this conjecture in the subsequent section on economies of scope. With respect to the control variables, there is a positive correlation between leverage and efficiency and no significant correlation between firm af-

Table 6
Results from DEA second stage regressions.

Variables	(1) SE	(2) PTE	(3) AE	(4) XE	(5) CE
lnAsset	0.0355***	−0.0202*	0.0322***	0.0123[a]	0.0269***
	(0.00652)	(0.0112)	(0.00894)	(0.00895)	(0.00877)
$lnAsset^2$	−0.00956***	0.00741***	−6.75e-05	0.00570**	−0.000842
	(0.00159)	(0.00244)	(0.00216)	(0.00248)	(0.00208)
Composite	0.0135	0.0100	−0.0666***	−0.0353*	−0.0185
	(0.0151)	(0.0329)	(0.0242)	(0.0209)	(0.0192)
Conglomerate	0.0185	0.0108	−0.0296	−0.0287	−0.0206
	(0.0184)	(0.0479)	(0.0369)	(0.0357)	(0.0305)
Leverage ratio	0.00466***	0.0161***	−0.00369	0.00804**	0.00953**
	(0.00151)	(0.00218)	(0.00367)	(0.00378)	(0.00398)
Unaffiliated	−0.0273	0.0330	−0.00147	0.0159	0.00387
	(0.0276)	(0.0451)	(0.0293)	(0.0276)	(0.0267)
Asia developed	0.00998	−0.0787	0.0519	−0.0301	−0.0364
	(0.0268)	(0.0783)	(0.0591)	(0.0380)	(0.0385)
Bermuda	−0.0322*	−0.121**	0.0408	−0.0564*	−0.0739**
	(0.0182)	(0.0488)	(0.0418)	(0.0334)	(0.0337)
London	−0.0486*	−0.207***	0.108**	−0.0444	−0.0548
	(0.0291)	(0.0661)	(0.0512)	(0.0772)	(0.0815)
Asia emerging	−0.128***	−0.182**	0.160***	−0.00521	−0.0849*
	(0.0481)	(0.0712)	(0.0410)	(0.0625)	(0.0461)
North America	−0.0361	−0.0494	0.0990**	0.0450	0.0240
	(0.0237)	(0.0749)	(0.0484)	(0.0571)	(0.0558)
Africa	−0.159***	−0.246***	0.219***	−0.00862	−0.0987**
	(0.0421)	(0.0658)	(0.0461)	(0.0472)	(0.0435)
Latin America	−0.0529	−0.0764	0.0705	−0.0325	−0.0345
	(0.0573)	(0.116)	(0.0726)	(0.0686)	(0.0676)
East Europe	−0.114***	−0.0225	0.113**	0.0880*	0.00280
	(0.0377)	(0.0566)	(0.0462)	(0.0476)	(0.0485)
Middle East	−0.136***	−0.157**	0.177***	0.0174	−0.0593
	(0.0332)	(0.0649)	(0.0424)	(0.0468)	(0.0446)
Year FE /constant	Yes	Yes	Yes	Yes	Yes
Overall R^2	0.577	0.353	0.374	0.461	0.568
Observations	841	841	841	841	841
Number of reinsurers	116	116	116	116	116

Notes: we present the results of the random effects panel regressions with robust standard errors clustered at the firm level provided in parentheses; *, **, *** represent statistical significance at the 10%, 5% and 1% level, respectively.
[a] P-value = 0.168.

filiation type and efficiency. Reinsurers based in Western Continental Europe, the reinsurance center of the world, are generally more cost efficient than, for example, reinsurers in emerging Asia or Bermuda.

4.4. Economies of scope

We follow an approach similar to Cummins et al., (2010) to assess the impact of scope on XE and its components, so as to make inferences about economies of scope.[18] We focus on XE because it represents the portion of CE that cannot be explained by economies of scale and, thus, allows for the assessment of pure cost scope economies (Cummins et al., 2010). The results in Columns (3) and (4) of Table 6 suggest that composite strategies (i.e., underwriting both life and nonlife business) increase the difficulty of a cost-efficient allocation of multiple inputs, thus decreasing AE as well as XE.

We further examine economies of scope for different firm sizes (Berger et al., 2000) by sorting our sample into small, medium, and large reinsurers as shown in Table 4. The results in Column (1) of Table 7 suggest that the negative impact of product diversification on XE only holds for small reinsurers, for which specialized strategies have higher XE than composite strategies. The observation supports H2A in the sense that small reinsurers perform better when specialized.

The results in Columns (2) and (3) show that for medium and large reinsurers, the impact of product diversification is insignificant. Alternatively, we test H2A and H2B by adding dummy variables for small-specialized and large-diversified reinsurers, as shown in Columns (4) and (5) of Table 7. The results confirm that small specialized (or focused) reinsurers have higher XE. These observations confirm H2A and explain why both specialized and diversified reinsurers can co-exist in the global reinsurance market. Concerning H2B, for large reinsurers, we find no significant evidence to support a conglomeration strategy; however, we are also not able to conclude on the opposite, i.e., a strategic focus strategy.

Based on these findings, we argue that the scope and scale of a reinsurer's operation must be compatible with each other for the firm to be efficient. Small reinsurers should be specialized, while large reinsurers may consider diversifying the scope of their business. 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.[19]

[18] An alternative way of analyzing economies of scope is to illustrate that the cost of jointly producing multiple outputs is less than separately producing these outputs (Berger et al., 2000). We cannot adopt this approach because our data do not allow the separation of losses between life and nonlife reinsurance business, nor between primary insurance and reinsurance. Furthermore, this approach requires specifying a cost function, yielding model misspecification risk. We analyze revenue scope economies in Section 4.6.

[19] We also consider the perspective of geographical diversification. The A.M. Best dataset contains only 70 observations having the information on pre-

Table 7
Scope impact on reinsurers.

Subsamples Variables	(1) Small XE	(2) Medium XE	(3) Large XE	(4) Full Sample XE	(5)
Composite	−0.121**	0.00450	−0.0607	0.00968	0.0200**
	(0.0476)	(0.0209)	(0.0799)	(0.00994)	(0.00975)
Conglomerate	−0.0125*	−0.000740	0.0197	0.00454*	0.00530**
	(0.00697)	(0.0322)	(0.0150)	(0.00245)	(0.00245)
lnAsset	−0.0959***	−0.0193	−0.0467	−0.0392	−0.0343
	(0.0258)	(0.0426)	(0.0494)	(0.0318)	(0.0210)
lnAsset^2	−0.00482	−0.00891	−0.0558	−0.0213	0.00516
	(0.0467)	(0.0473)	(0.0631)	(0.0369)	(0.0466)
Leverage ratio	0.0394***	0.000663	0.0169***	0.00782**	0.00819**
	(0.0108)	(0.00283)	(0.00556)	(0.00374)	(0.00354)
Unaffiliated	−0.0291	−0.0457	0.0908	0.0106	0.0101
	(0.0280)	(0.0300)	(0.112)	(0.0256)	(0.0275)
Small*Specialized				0.0406*	
				(0.0248)	
Large*Composite				0.0571	
				(0.0495)	
Small*Focused					0.0472**
					(0.0185)
Large*Conglomerate					−0.0443
					(0.0614)
Asia developed	0.107	−0.0599	0.0139	−0.0281	−0.0302
	(0.0916)	(0.0489)	(0.0858)	(0.0398)	(0.0379)
Bermuda	−0.0107	−0.139***	0.0484	−0.0693**	−0.0590*
	(0.0857)	(0.0457)	(0.0429)	(0.0337)	(0.0333)
London	−0.0286	−0.0492	0.0549	−0.0385	−0.0459
	(0.0982)	(0.0865)	(0.127)	(0.0789)	(0.0775)
Asia emerging	0.0243	−0.123**	0.182	−0.0208	−0.00892
	(0.0762)	(0.0504)	(0.185)	(0.0578)	(0.0630)
North America	−0.0152	−0.0234	0.117	0.0555	0.0496
	(0.0759)	(0.0893)	(0.0885)	(0.0592)	(0.0584)
Africa	0.0923	−0.0391		0.00427	−0.0151
	(0.0885)	(0.0621)		(0.0493)	(0.0465)
Latin America	0.0175		0.270***	−0.0316	−0.0351
	(0.0827)		(0.0356)	(0.0623)	(0.0697)
East Europe	0.0667	−0.0202	0.139	0.0729	0.0779*
	(0.0790)	(0.0650)	(0.101)	(0.0460)	(0.0471)
Middle East	0.128	−0.0693		0.0141	0.00672
	(0.0823)	(0.0437)		(0.0452)	(0.0451)
Overall R^2	0.496	0.518	0.531	0.466	0.461
Observations	284	281	276	841	841
Number of reinsurers[a]	53	52	38	116	116

Notes: we present the results of the random effects panel regressions with robust standard errors clustered at the firm level provided in parentheses.
[a] The unbalanced number of observations follows from the sorting of reinsurers by size in each year separately as opposed to a sorting based on the complete sample including all years. Thus, the categories are only mutually exclusive for single observations, but not for reinsurers because one reinsurer might fall in one size category in one year and in larger or smaller size category in a subsequent year. For this reason, the total number of reinsurers across the three size groups (i.e., 143) is also larger than the complete sample of 116 reinsurers, whereas the total number of observations across the three size groups is equal to 841. *, **, *** represent statistical significance at the 10%, 5%, and 1% level, respectively.

4.5. Efficient structure

Following Berry-Stölzle, Weiss, and Wende (2011), Choi and Weiss (2005), and Weiss and Choi (2008), we test the ES hypothesis by estimating the reinsurers' price and underwriting profit separately based on Eqs. (2) and (3). As suggested by Berger (1995), we include both SE and XE measures in the regression, together with market share and concentration measures. This approach has been shown as a valid reduced form for the ES hypothesis and the competing RMP and SCP hypotheses (Berger, 1995).

$$\begin{aligned} Profit_{i,t} &= \beta_0 + \beta_1 X\_Efficiency_{i,t} + \beta_2 Scale\ Efficiency_{i,t} \\ &\quad + \beta_3 MarketShare_{i,t} + \beta_4 MarketConcentration_t \\ &\quad + \beta_5 MarketGrowth_t + \beta_j X_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (2)$$

$$\begin{aligned} Price_{i,t} &= \beta_0 + \beta_1 X\_Efficiency_{i,t} + \beta_2 Scale\ Efficiency_{i,t} \\ &\quad + \beta_3 MarketShare_{i,t} + \beta_4 MarketConcentration_t \\ &\quad + \beta_5 MarketGrowth_t + \beta_j X_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (3)$$

We measure the reinsurance unit price as the inverse of the smoothed loss ratio minus one, i.e., premium divided by the smoothed loss minus one (Cummins and Danzon, 1997; Winter, 1994).[20] The underwriting profit is defined as one minus the smoothed loss ratio minus the expense ratio (Choi and Weiss, 2005; Weiss and Choi, 2008). We consider ROA to measure the overall profitability of a reinsurer. We use ROA instead of ROE be-

mium geographical distribution in our sample. Based on this subsample, we test whether a specialized reinsurer must be geographically diversified to be efficient (Ma and Elango, 2008). The results (available from the authors upon request) are insignificant, which might however be driven by the small sample size.

[20] The rate on line (ROL, reinsurance premium divided by reinsurance limit) is a sound candidate of the price of risk pooling; however, this type of information is not reported in regular financial statements in most markets and also not captured in our dataset.

Table 8
Results for efficient structure hypothesis.

Variables	Price	UW Profit	ROA	Price	UW Profit	ROA
CE	−0.144***	8.618***	−0.848			
	(0.0260)	(2.414)	(1.035)			
SE				−0.0764**	5.848**	−1.822
				(0.0325)	(2.445)	(1.125)
XE				−0.121***	6.870***	−0.219
				(0.0264)	(2.326)	(1.043)
Market share	0.000445*	−0.0615*	0.0629***	0.000434*	−0.0626*	0.0644***
	(0.000246)	(0.0342)	(0.0210)	(0.000246)	(0.0331)	(0.0207)
Market concentration	0.0356	24.18	6.364	0.0353	24.25	5.687
	(0.449)	(31.77)	(5.978)	(0.441)	(31.48)	(5.967)
Market growth	0.0597	0.0518	−1.777	0.0690	−1.323	−0.724
	(0.0879)	(7.724)	(2.896)	(0.0897)	(7.993)	(2.849)
Leverage ratio	−0.00852***	−0.375**	−0.501***	−0.00843***	−0.388**	−0.492***
	(0.00274)	(0.159)	(0.0970)	(0.00259)	(0.166)	(0.0956)
Unaffiliated	0.0144	−2.428	−0.203	0.0140	−2.273	−0.341
	(0.0310)	(2.758)	(0.679)	(0.0317)	(2.773)	(0.708)
Asia developed	0.0175	2.023	−0.843	0.0193	1.788	−0.734
	(0.0451)	(4.075)	(0.975)	(0.0453)	(4.049)	(0.991)
Bermuda	0.0554	−0.200	2.639	0.0562	−0.225	2.608
	(0.0392)	(3.119)	(1.751)	(0.0392)	(3.095)	(1.749)
London	0.112**	−4.882	−0.233	0.108**	−4.602	−0.359
	(0.0503)	(5.768)	(1.195)	(0.0508)	(5.571)	(1.209)
Asia emerging	0.0713	0.972	−0.420	0.0718	1.105	−0.632
	(0.0645)	(4.618)	(1.245)	(0.0630)	(4.582)	(1.302)
North America	0.00439	0.432	5.189	0.00336	0.526	5.123
	(0.0512)	(3.141)	(4.677)	(0.0507)	(3.127)	(4.693)
Africa	0.170***	2.200	0.804	0.169***	2.453	0.555
	(0.0417)	(3.666)	(0.803)	(0.0403)	(3.618)	(0.824)
Latin America	0.122**	−0.991	1.366	0.119*	−0.521	1.066
	(0.0618)	(4.520)	(1.100)	(0.0619)	(4.422)	(1.097)
East Europe	0.0109	0.213	0.168	0.0111	0.505	−0.194
	(0.0296)	(4.628)	(0.890)	(0.0300)	(4.523)	(0.914)
Middle East	−0.0575	−5.968	−2.788**	−0.0590	−5.655	−3.054**
	(0.0405)	(4.273)	(1.236)	(0.0410)	(4.234)	(1.262)
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	No	No	No	No
Overall R^2	0.319	0.064	0.114	0.321	0.070	0.116
Observations	841	841	841	841	841	841
Number of reinsurers	116	116	116	116	116	116

Notes: we present the results of the random effects panel regressions with robust standard errors clustered at the firm level provided in parentheses; *, **, *** represent statistical significance at the 10%, 5% and 1% level, respectively.

cause industry ROE is used as the price of capital in the process of estimating efficiency and, thus, might not be appropriate as a dependent variable. CE, SE, and XE are used for efficiency measures. Other explanatory 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. The series of control variables, X, includes the leverage ratio, affiliation status, and headquarter location dummies (i.e., market fixed effects). Different from Eq. (1), year dummies are not included in Eqs. (2) and (3) due to the potential multicollinearity with market growth and market concentration.[21]

The results in Table 8 show that CE and its components XE and SE are negatively correlated with price, positively correlated with underwriting profit, and have no significant impact on overall profitability. These results support H3 in the sense that cost-efficient reinsurers can charge lower prices while preserving profitability. The correlations between market share (market concentration) and both price and profit are insignificant, a finding that does not support the RMP (SCP) hypotheses.

[21] We examine multicollinearity by estimating the VIFs of each independent variable in Equations (1) to (3). All values are below 5, suggesting that multicollinearity is not a serious problem in our analyses.

4.6. Additional tests

4.6.1. Returns to scale analysis

For the discrete returns to scale categories IRS, CRS, and DRS, we conduct a multinomial logistic regression (Greene, 2012) to identify factors impacting the probability of falling in one of the three distinct categories as follows (Cummins and Xie, 2013):

$$RTS_{i,t} = \beta_0 + \beta_1 Scale_{i,t} + \beta_2 Scale_{i,t}{}^2 + \beta_3 Scope_i + \beta_j X_{i,t} + \varepsilon_{i,t} \quad (4)$$

The explanatory variables used in Eq. (4) are the same as those in Eq. (1). This additional analysis improves the reliability of our conclusions on economies of scale (H1A) and scope (H2). The results in Table 9 show that the probability of operating under IRS is negatively related to firm size, and the probability of operating under CRS and DRS is positively related to firm size. The impact of size on the probability of operating under DRS is significantly larger than its impact on CRS, subject to a t-test (p-value = 0.015). This additional evidence again supports H1A in the sense that small reinsurers are more likely to operate under IRS, medium-sized reinsurers are more likely to operate under CRS, and the largest reinsurers are more likely to operate under DRS.

Complexity theory suggests that X may relate to Y positively, negatively, or not at all within the same set of data, which is contingent on various antecedents and configurations (Woodside, 2014). Therefore, we also test whether SE is contingent

Table 9
Determinants of returns to scale.

Variables	IRS	CRS	DRS
lnAsset	−0.163***	0.0199**	0.143***
	(0.0511)	(0.00801)	(0.0501)
lnAsset^2	−0.00564	0.00341**	0.00222
	(0.00922)	(0.00172)	(0.00838)
Composite	0.0467	−0.0106	−0.0361
	(0.0337)	(0.0156)	(0.0279)
Conglomerate	0.0807**	−0.0164	−0.0643*
	(0.0366)	(0.0140)	(0.0331)
Leverage ratio	0.01000	0.00540***	−0.0154*
	(0.00839)	(0.00153)	(0.00839)
Unaffiliated	−0.0165	0.0294	−0.0128
	(0.0416)	(0.0364)	(0.0401)
Asia developed	−0.0540	−0.0135	0.0675
	(0.0751)	(0.0163)	(0.0775)
Bermuda	−0.0171	−0.0208	0.0379
	(0.0488)	(0.0140)	(0.0438)
London	0.0333	−0.0174	−0.0159
	(0.0401)	(0.0162)	(0.0349)
Asia emerging	−0.0947	−0.0333***	0.128
	(0.0907)	(0.00921)	(0.0900)
North America	−0.0320	−0.00837	0.0404
	(0.0602)	(0.0180)	(0.0555)
Africa	−0.0927	−0.106***	0.199
	(0.215)	(0.0271)	(0.213)
Latin America	−0.322	−0.00430	0.326*
	(0.205)	(0.0460)	(0.178)
East Europe	−0.373	−0.0229	0.396
	(0.274)	(0.0143)	(0.274)
Middle East	−0.00476	−0.0265**	0.0312
	(0.122)	(0.0124)	(0.121)
Year FE/constant	Yes	Yes	Yes
Pseudo R^2		0.451	
Observations	841	841	841
Number of reinsurers	116	116	116

Notes: we present the marginal effects of multinomial logistic regression with robust standard errors clustered at the firm level provided in parentheses; *, **, *** represent statistical significance at 10%, 5% and 1% level, respectively.

on reinsurer's scope. The results in Table 9 suggest that product-diversified reinsurers are more likely to operate under IRS than focused reinsurers, and less likely to operate under DRS. This is particularly true when considering the product diversification across primary insurance and reinsurance. Similar patterns are also found in the primary insurance market (Cummins and Xie, 2013).

One explanation is that product diversification increases the size required for a firm to become scale efficient, such that firms expanding scope need time to grow to a new optimal size (Cummins and Xie, 2013). In other words, more diversified firms must be larger to reach scale efficiency. After increasing scope, firms originally operating under DRS become IRS or CRS, and firms originally operating under CRS become IRS. This also explains the insignificant impact of scope on SE (Column (1) of Table 6) and on the probability of operating under CRS (Column (2) of Table 9). This finding is consistent with the rationale that scope and scale of a reinsurer must match.

4.6.2. Granger causality test

Our hypotheses suggest that CE increases with scale and prices decrease with CE. Thus, lower prices potentially attract more clients and, subsequently, increase firm scale. The empirical evidence presented here is consistent with these predictions. However, a significant coefficient does not necessarily provide information regarding its causality. Therefore, we employ a Granger causality test to discriminate whether a reinsurer's scale drives its CE or vice versa (Berger and DeYoung, 1997; Casu and Girardone, 2009). Granger causality contains two important premises: first, if A Granger causes B, then A must occur earlier than B; and second, A must contain useful information that can predict B (Granger, 1969).

Based on the following Eq. (5), we test the null hypothesis ($H.A_0$) that size does not Granger cause CE, i.e., $\beta_{1,1} = \beta_{1,2} = \ldots = \beta_{1,n} = 0$:

$$\begin{aligned} CE_{i,t} =& \beta_0 + \sum^{\beta_{1,n}} Size_{i,t-n} + \beta_2 Composite_i + \beta_3 Conglomerate_i \\ &+ \sum^{\beta_{3,n}} CE_{i,t-n} + \beta_j X_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{5}$$

Based on the following Eq. (6), we test for the reverse causality ($H.B_0$) that CE does not Granger cause size, i.e., $\beta_{3,1} = \beta_{3,2} = \ldots = \beta_{3,n} = 0$:

$$\begin{aligned} Size_{i,t} =& \beta_0 + \sum\nolimits^{\beta_{1,n}} Size_{i,t-n} + \beta_2 Composite_i + \beta_3 Conglomerate_i \\ &+ \sum\nolimits^{\beta_{3,n}} CE_{i,t-n} + \beta_j X_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{6}$$

We perform nested F-tests for each regression with $n = 1,2,\ldots 8$ and show the resulting p-values in Table 10, 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 values except $n = 3$ at the 90% confidence level and accept $H.B_0$ for all n values.[22] Therefore, we conclude that size Granger causes cost efficiency and we do not find evidence of reverse causality.

The reverse causality, i.e., higher CE inducing higher market share and larger size, is embedded in the ES rationale (H3). We are not able to empirically confirm this direction of causality, probably because the causality chain and the time to establish the link from high CE to low prices and finally to larger scale are rather long term. It takes time for a cost-efficient reinsurer to significantly grow or find a proper acquiring target, particularly considering the fierce reinsurance market competition and that corporate clients prefer stable and long-term relationships. Hence, our sample with a maximum of eight-year lags is relatively short to capture the efficient-growth causality.

4.6.3. Revenue scope economies

Thus far, we have focused on the impact of scale and scope on cost efficiency and its components. However, a prominent motivation for a reinsurer to operate across product lines is the benefit of cross selling, which results in revenue scope economies. Berger et al., (2000) suggest that revenue efficiency is important when consumers are willing to pay for the extra convenience of one-stop shopping. We expect, however, different potential for revenue scope economies with regard to (1) multi-line operations across life and nonlife reinsurance and (2) across reinsurance and primary insurance. This is because buyers of life and nonlife reinsurance might be the same primary insurers, thus benefiting from one-stop shopping, whereas buyers of primary insurance (i.e., policyholders) and buyers of reinsurance (i.e., primary insurers) are usually not the same entities. Thus, the cross-selling benefits of primary insurance and reinsurance are limited.

We use the same DEA approach to estimate revenue efficiency frontiers separately for each year between 2002 and 2012. The prices for the two outputs (smoothed loss and total invested

[22] 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 (5) and at n=2 for Equation (6). We also consider whether size and cost efficiency are stationary in the panel sample. We perform a Fisher-type unit root test for our unbalanced panel. The results reject the null hypothesis that all panels contain unit roots and support the alternative hypothesis that at least one panel is stationary. We also reduce our sample to a balanced panel by removing firms with missing years and perform Harris-Tzavalis (Im-Pesaran-Shin) unit-root tests. The results again reject the null hypotheses that (all) panels contain unit roots and support the alternative hypothesis that (some) panels are stationary.

Table 10
Granger causality test.

	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 Eq. (5)	0.004	0.012	0.108	0.008	0.003	0.073	0.080	0.045
$H.B_0$ in Eq. (6)	0.551	0.313	0.260	0.390	0.239	0.441	0.735	0.229
Number of observations	706	586	474	373	289	214	149	108
Number of reinsurers	109	104	97	84	75	65	41	39

Table 11
Revenue scope efficiency scores.

Sample	Definition	Mean	Std. dev.	Observations	P-value[a]
Specialized	Only life or nonlife	0.438	0.240	463	0.038
Diversified	Life and nonlife	0.474	0.260	378	
Focused	Only reinsurance	0.449	0.249	708	0.149
Conglomerate	Direct and reinsurance	0.483	0.250	133	
Full sample		0.454	0.250	841	

Note:
[a] P-value of mean difference *t*-test.

assets) are required additionally to calculate revenue efficiency. We follow the practice in Section 4.5 using the inverse of the smoothed loss ratio minus one as the price for the risk pooling function (Cummins and Danzon, 1997; Winter, 1994). We then use the annual realized industry-wide investment returns – an approximation of the expected investment returns – as the price for the financial intermediary function (Cummins and Weiss, 2013); this practice is also consistent with using industry ROE as the price of capital.

Table 11 presents the average revenue efficiency scores for the full sample and for the subsamples of specialized vs. composite and focused vs. conglomerate reinsurers, respectively. The p-values of the mean difference *t*-tests suggest that reinsurers operating in both life and nonlife reinsurance are significantly more revenue efficient than reinsurers operating only in life or nonlife reinsurance. Furthermore, the difference between pure reinsurers and reinsurers that also underwrite primary insurance is insignificant. These findings are consistent with our expectations.

To analyze the impact of scope on revenue efficiency, we estimate Eq. (1) using revenue efficiency scores as dependent variable. The results in Column (1) of Table 12 show a positive and significant coefficient for the composite dummy, but an insignificant coefficient for the conglomerate dummy. The results are in line with our expectations in the sense that operating across life and nonlife reinsurance has additional revenue efficiency benefits compared to single-line operations. However, such revenue scope economies do not exist across reinsurance and primary insurance operations.

We further separate our sample into small, medium, and large reinsurers. We find that revenue scope economies do not exist for small reinsurers, may exist but are weak for medium reinsurers (p-value = 0.132), and are significantly positive for large reinsurers (p-value = 0.070). This result is consistent with H2B in the sense that product diversification improves revenue efficiency of large reinsurers. This finding again suggests that scale and scope of a reinsurer must match: large reinsurers gain additional revenue efficiency by product diversification across life and nonlife reinsurance, while small reinsurers may not have this advantage but generate additional costs.

4.6.4. Robustness checks

We additionally perform robustness checks in three categories. All results are available from the authors upon request and support our conclusions, unless otherwise stated in this section.

We check whether our results are sensitive to alternative inputs and outputs and their respective prices. First, we use reinsurers' net premiums written as an alternative output to replace the smoothed loss, which represents the risk pooling function (Cummins and Weiss, 2013). Second, we consider the following alternative input prices: market specific MSCI yearly total return indices to replace the industry ROE as the equity capital price, and the Producer Price Indices (PPI) to replace the CPI as the price for materials and business services.

We further test the robustness of our conclusions regarding alternative specifications of our estimation techniques. First, as suggested by Simar and Wilson (2000), we apply the double bootstrapping procedure in both the first- and second-stage DEA analyses with 2000 replications. Second, 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. Third, we use firm and year fixed effects models to replace the random effects models (with market and year dummies) for DEA second-stage regressions.

Finally, to test the dependency of our conclusions on sample selection, we use a subsample that includes only observations without any missing values, since missing values for the number of employees were imputed for some data points in our core models. We also separate our sample into two time periods: before the financial crisis (2002–2007) and after (2008–2012). The decile and vigintile analyses suggest that there is no structural change regarding the optimal size range before and after the financial crisis. Finally, we separate our sample by region into mature markets and emerging markets. 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. Further, mature markets demonstrate a pattern similar to that of the global market (see Table 5). These analyses confirm the robustness of our optimal asset range of between USD 2.9 and 15.5 billion.

5. Conclusions

Our paper contributes to the finance and insurance literature by deriving four original conclusions. First, scale-efficient reinsurers exhibit an optimal size range between USD 2.9 and 15.5 billion in total assets (inflation adjusted to 2012), beyond which scale economies are exhausted. These thresholds are larger than those for the primary insurance market or other financial service industries. Second, the high cost-efficiency levels of large reinsurers are partially a result of their size. Third, a strategic focus strategy is appropriate for small reinsurers, whereas a product diversification strategy may suit some large reinsurers due to significant revenue

Table 12
Determinants of revenue efficiency.

Sample	(1) Full sample	(2)	(3) Small	(4) Medium	(5) Large
Variables	RE	RE	RE	RE	RE
Composite	0.0571**	0.0558**	0.000995	0.0811[a]	0.0826*
	(0.0283)	(0.0279)	(0.0457)	(0.0538)	(0.0457)
Conglomerate	0.0313				
	(0.0415)				
lnAsset	−0.00528	−0.00372	−0.0646	0.0373	−0.101
	(0.00891)	(0.00844)	(0.0540)	(0.0266)	(0.0886)
$\ln Asset^2$	−0.00374*	−0.00360*	−0.00831	−0.0548	0.0140
	(0.00216)	(0.00217)	(0.00909)	(0.0374)	(0.0145)
Leverage ratio	0.0214***	0.0212***	0.0337**	0.0132***	0.0257***
	(0.00187)	(0.00183)	(0.0135)	(0.00403)	(0.00432)
Unaffiliated	0.0122	0.0117	0.0180	0.00195	0.181**
	(0.0383)	(0.0381)	(0.0488)	(0.0485)	(0.0827)
Asia developed	−0.118	−0.119	−0.140	−0.161**	−0.127
	(0.0749)	(0.0747)	(0.187)	(0.0626)	(0.0856)
Bermuda	−0.144***	−0.138***	−0.244**	−0.106	−0.0486
	(0.0439)	(0.0419)	(0.111)	(0.0757)	(0.0480)
London	−0.177**	−0.174**	−0.339***	−0.0949	−0.0231
	(0.0715)	(0.0698)	(0.107)	(0.0792)	(0.153)
Asia emerging	−0.208***	−0.204***	−0.365***	−0.0754	−0.0628
	(0.0542)	(0.0553)	(0.114)	(0.0667)	(0.134)
North America	−0.0643	−0.0551	−0.274**	−0.152	0.106
	(0.0670)	(0.0627)	(0.114)	(0.0938)	(0.0767)
Africa	−0.329***	−0.324***	−0.434***	−0.176**	
	(0.0578)	(0.0558)	(0.126)	(0.0683)	
Latin America	−0.153*	−0.151*	−0.303**		0.0536
	(0.0867)	(0.0865)	(0.123)		(0.0464)
East Europe	−0.112**	−0.107**	−0.260**	−0.0773	−0.0322
	(0.0508)	(0.0492)	(0.103)	(0.0779)	(0.0703)
Middle East	−0.252***	−0.251***	−0.374***	−0.152**	
	(0.0537)	(0.0536)	(0.122)	(0.0623)	
Constant/Year FE	Yes	Yes	Yes	Yes	Yes
Overall R^2	0.525	0.527	0.489	0.558	0.664
Observations	841	841	284	281	276
No. of reinsurers	116	116	53	52	38

Notes: we present the results of the random effects panel regressions with robust standard errors clustered at the firm level provided in parentheses; *, **, *** represent statistical significance at the 10%, 5% and 1% level, respectively.
[a] P-value = 0.132.

scope economies. Fourth, cost-efficient reinsurers can charge lower prices without sacrificing profitability.

Our results provide new insights into the effects of economies of scale and scope in the global reinsurance market. The overall cost efficiency of large reinsurers explains their dominating position in the global market. The high pure technical efficiency of small specialized reinsurers and the high revenue efficiency of large diversified reinsurers provide a rationale for concurrent long run competitiveness of both product-diversified and specialized firms. These results also explain the paradoxical ability of inefficient firms to survive for many years. Some of these firms, particularly small firms, although cost inefficient, may have strong pure technical efficiency in their specialized field, and, thus, are viable over the long term.

Our findings have both regulatory policy and managerial practice implications. Further consolidation is expected in the global reinsurance market, not only because it improves cost efficiency, but also because it has the potential to lower reinsurance prices for consumers. Therefore, policymakers should be cautious when 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 firm management point of view, consolidation is not without its disadvantages, especially when considering the limitations of 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 the largest reinsurers. At this point, we cannot be sure that technology and management progress will adapt sufficiently fast 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 reinsurance management to carefully evaluate the trade-offs between scale diseconomies and gains in X-efficiency, especially for reinsurers beyond the optimal size range, when considering merger and acquisition opportunities. Reinsurers should also be careful when evaluating conglomerate versus focused strategies. Specifically, small reinsurers must be cautious about product diversification (i.e., adding life reinsurance to their nonlife reinsurance business or vice versa), as doing so could significantly reduce cost efficiency.

These findings contribute to the recent discussion on systemic risk in the insurance and reinsurance industry (Cummins and Weiss, 2014; Park and Xie, 2014) by analyzing the extent to which size and diversification can be justified by efficiency considerations. We analyze efficiency in a way not yet considered in the current systemic risk discussion, which therefore provides an alternative line of reasoning. For example, if regulators require large reinsurers to hold more equity capital, this would deteriorate their cost efficiency advantages and affect market structure. 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 Berger et al., 1987).

Empirical research on global reinsurance markets is far from conclusive and this study is not without limitations, which provide opportunities for future research. Future research may provide more detailed guidance to reinsurers and policymakers as to which inputs or outputs reinsurers can reduce or increase to be more efficient. Research on the impact of geographic and international diversification is also lacking due to limited data availability. Particularly, an interesting direction to investigate is why product specialized reinsurers can also be rather efficient, which could be explained by the interactions between geographical diversification and product diversification (Ma and Elango, 2008). Moreover, 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 and Louberge, 1996), providing another direction for future empirical investigation.

Appendix A

Table A1
Geographical and yearly sample distribution.

Panel A: Geographical distribution			*Panel B: Yearly distribution*		
Domiciled location	Firm-years	%	Year	Firms	%
(Western) Continental Europe	208	24.7	2002	46	5.5
Bermuda	160	19.0	2003	52	6.2
Africa	77	9.2	2004	50	5.9
Asia Developed	65	7.7	2005	50	5.9
East Europe	64	7.6	2006	80	9.5
North America	63	7.5	2007	81	9.6
Middle East	60	7.1	2008	81	9.6
Asia Emerging	54	6.4	2009	97	11.5
London	54	6.4	2010	105	12.5
Latin America	36	4.3	2011	101	12.0
			2012	98	11.7
Total	841	100	Total	841	100

Notes: continental Europe hosts the largest proportion of reinsurers, whereas Bermuda has the second largest share. London, traditionally one of the major reinsurance hubs, hosts only 6.3% of reinsurers because we exclude Lloyd's syndicates from our sample. In addition, the London market suffered huge losses during the liability crisis in the 1980s and from natural catastrophes. Hence, many London players were merged with other reinsurers (Holzheu and Lechner, 2007). The relative small portion of North American reinsurers is due to U.S. primary insurers preferring to reinsure with foreign reinsurers based on diversification concerns (Chen and Hamwi, 2000), and the strong emergence of the Bermuda market. The Canadian reinsurance market is underdeveloped because large state-owned insurers rarely use reinsurance (Holzheu and Lechner, 2007).

Appendix B

B.1. Loss smoothing procedure

We smooth the output of the loss following the two-step procedure proposed by Cummins and Xie (2008). First, we rank the reinsurers by their net premiums written in each year. Reinsurers who rank in the top 80% are considered representative companies. The remaining 20% are the smallest companies. We then determine the 25th and 75th percentiles of the loss ratio of those representative reinsurers in each year. For reinsurers with loss ratios between the 25th and 75th percentile, we use their actual loss ratio to calculate the output quantity of the loss. For reinsurers with loss ratios below the 25th percentile or above the 75th percentile, we use the 25th and 75th percentile loss ratios, respectively, to calculate the output quantity of the loss. The first step is a winsorising process on representative reinsurers. Second, for each firm in the sample, we fit a linear time trend to the new series of the loss ratios obtained in the first step and then calculate a smoothed loss ratio series. The linear trend regression for each firm-year is $Loss\ Ratio_{i,t} = \beta_i + \beta_i t + \varepsilon_{i,t}$, where i represents the reinsurer and t represents the year. We then use the predicted loss ratio values as smoothed loss ratios and use the smoothed loss ratio multiplied by the net premiums written of respective firm-years to generate the smoothed loss.

References

A.M. Best. 2002–2012. Best's Insurance Reports, databases version 2007, 2010, and 2013.
A.M. Best. Global reinsurance segment review: the capital challenge.
Aly, H.Y., Grabowski, R., Pasurka, C., Rangan, N., 1990. Technical, scale, and allocative efficiencies in US banking: an empirical investigation. Rev. Econ.Stat. 72 (2), 211–218.
Beaver, W.H., McNichols, M.F., Nelson, K.K., 2003. Management of the loss reserve accrual and the distribution of earnings in the property-casualty insurance industry. J. Accounting Econ. 35 (3), 347–376.
Berger, A.N., 1995. The profit-structure relationship in banking–tests of market-power and efficient-structure hypotheses. J. Money, Credit Banking 27 (2), 404–431.
Berger, A.N., Cummins, J.D., Weiss, M.A., Zi, H., 2000. Conglomeration versus strategic focus: evidence from the insurance industry. J. Financ. Intermediation 9 (4), 323–362.
Berger, A.N., DeYoung, R., 1997. Problem loans and cost efficiency in commercial banks. J. Banking Finance 21 (6), 849–870.
Berger, A.N., Hanweck, G.A., Humphrey, D.B., 1987. Competitive viability in banking: scale, scope, and product mix economies. J. Monetary Econ. 20 (3), 501–520.
Berger, A.N., Humphrey, D.B., 1991. The dominance of inefficiencies over scale and product mix economies in banking. J. Monetary Econ. 28 (1), 117–148.
Berger, A.N., Humphrey, D.B., Pulley, L.B., 1996. Do consumers pay for one-stop banking? evidence from an alternative revenue function. J. Banking Finance 20 (9), 1601–1621.
Bernard, C., 2013. Risk sharing and pricing in the reinsurance market. In: Dionne, G. (Ed.), Handbook of Insurance. Springer, New York.
Berry-Stölzle, T.R., Weiss, M.A., Wende, S., 2011. Market structure, efficiency, and performance in the European property-liability insurance industry, Working paper.
Biener, C., Eling, M., Wirfs, J.H., 2015. The determinants of efficiency and productivity in the Swiss insurance industry. Eur. J. Oper. Res. forthcoming.
Bikker, J.A., Gorter, J., 2011. Restructuring of the Dutch nonlife insurance industry: consolidation, organizational form, and focus. J. Risk Insurance 78 (1), 163–184.
Borch, K., 1960. The safety loading of reinsurance premiums. Scandinavian Actuarial J. 3–4, 163–184.
Borch, K., 1962. Equilibrium in a reinsurance market. Econometrica 30 (3), 424–444.
Butt, M., 2007. Insurance, finance, Solvency II and financial market interaction. Geneva Pap. Risk Insurance 32 (1), 42–45.
Casu, B., Girardone, C., 2009. Testing the relationship between competition and efficiency in banking: a panel data analysis. Econ. Lett. 105 (1), 134–137.
Chen, Y., Hamwi, I.S., 2000. Performance analyses of US property-liability reinsurance companies. J. Insurance Issues 23 (2), 140–152.
Choi, B.P., Weiss, M.A., 2005. An empirical investigation of market structure, efficiency, and performance in property-liability insurance. J. Risk Insurance 72 (4), 635–673.
Clark, J.A., 1988. Economies of scale and scope at depository financial institutions: a review of the literature. Econ. Rev. 73 (8), 17–33.
Cole, C., Ferguson, W., Lee, R., McCullough, K., 2010. Internationalization of the reinsurance industry: an analysis of the net exposure of reinsurers, Working paper.
Cole, C.R., Lee, R.B., McCullough, K.A., 2007. A test of the eclectic paradigm: evidence from the US reinsurance market. J. Risk Insurance 74 (2), 493–522.
Cole, C.R., McCullough, K.A., 2006. A reexamination of the corporate demand for reinsurance. J. Risk Insurance 73 (1), 169–192.
Cole, C.R., McCullough, K.A., 2008. A comparative analysis of US property and casualty reinsurers and insurers. Risk Manage. Insurance Rev. 11 (1), 179–207.
Cook, W.D., Zhu, J., 2014. Data Envelopment Analysis: A Handbook on the Modeling of Internal Structures and Networks. Springer, New York.
Cooper, W.W., Seiford, L.M., Zhu, J., 2011. Data envelopment analysis: history, models, and interpretations. In: Cooper, W.W., Seiford, L.M. (Eds.), Handbook on Data Envelopment Analysis. Springer, New York.
Cummins, J.D., Danzon, P.M., 1997. Price, financial quality, and capital flows in insurance markets. J. Financ. Intermediation 6 (1), 3–38.
Cummins, J.D., Tennyson, S., Weiss, M.A., 1999. Consolidation and efficiency in the US life insurance industry. J. Banking Finance 23 (2), 325–357.
Cummins, J.D., Weiss, M.A., 2000. The global market for reinsurance: consolidation, capacity, and efficiency. Brookings-Wharton Pap. Financ. Ser. 3 (2000), 159–209.
Cummins, J.D., Weiss, M.A., 2009. Convergence of insurance and financial markets: hybrid and securitized risk-transfer solutions. J. Risk Insurance 76 (3), 493–545.
Cummins, J.D., Weiss, M.A., 2013. Analyzing firm performance in the insurance industry using frontier productivity and efficiency methods. In: Dionne, G. (Ed.), Handbook of Insurance. Springer, New York.
Cummins, J.D., Weiss, M.A., 2014. Systemic risk and the US insurance sector. J. Risk Insurance 81 (3), 489–528.

Cummins, J.D., Weiss, M.A., Xie, X., Zi, H., 2010. Economies of scope in financial services: A DEA efficiency analysis of the US insurance industry. J. Banking Finance 34 (7), 1525–1539.
Cummins, J.D., Xie, X., 2008. Mergers and acquisitions in the US property-liability insurance industry: productivity and efficiency effects. J. Banking Finance 32 (1), 30–55.
Cummins, J.D., Xie, X., 2013. Efficiency, productivity, and scale economies in the US property-liability insurance industry. J. Productivity Anal. 39 (2), 141–164.
Cummins, J.D., Zi, H., 1998. Comparison of frontier efficiency methods: an application to the US life insurance industry. J. Productivity Anal. 10 (2), 131–152.
Curi, C., Lozano-Vivas, A., Zelenyuk, V., 2015. Foreign bank diversification and efficiency prior to and during the financial crisis: does one business model fit all? J. Banking Finance forthcoming.
Demsetz, H., 1973. Industry structure, market rivalry, and public policy. J. Law Econ. 16 (1), 1–9.
Eckles, D.L., Hoyt, R.E., Miller, S.M., 2014. The impact of enterprise risk management on the marginal cost of reducing risk: evidence from the insurance industry. J. Banking Finance 43 (C), 247–261.
Elango, B., Ma, Y.L., Pope, N., 2008. An investigation into the diversification-performance relationship in the US property-liability insurance industry. J. Risk Insurance 75 (3), 567–591.
Eling, M., Luhnen, M., 2010. Frontier efficiency methodologies to measure performance in the insurance industry: overview, systematization, and recent developments. Geneva Pap. Risk Insurance 35 (2), 217–265.
Farrell, M.J., 1957. The measurement of productive efficiency. J. R. Stat. Soc. Series A (General) 253–290.
Garven, J.R., Louberge, H., 1996. Reinsurance, taxes, and efficiency: a contingent claims model of insurance market equilibrium. J. Financ. Intermediation 5 (1), 74–93.
Granger, C.W., 1969. Investigating causal relations by econometric models and cross-spectral methods. Econometrica 37 (3), 424–438.
Greene, W.H., 2012. Econometric Analysis, 7th ed Prentice Hall, Upper Saddle River, New Jersey.
Greene, W.H., Segal, D., 2004. Profitability and efficiency in the US life insurance industry. J. Productivity Anal. 21 (3), 229–247.
Holzheu, T., Lechner, R., 2007. The global reinsurance market. In: Cummins, D.J., Vendard (Eds.), Handbook of International Insurance. Springer, New York, NY.
Kader, H.A., Adams, M., Mouratidis, K., 2010. Testing for trade-offs in the reinsurance decision of UK life insurance firms. J. Accounting, Auditing Finance 25 (3), 491–522.
Katrishen, F.A., Scordis, N.A., 1998. Economies of scale in services: a study of multinational insurers. J. Int. Bus. Stud. 29 (2), 305–323.
Klarner, P., Raisch, S., 2013. Move to the beat–Rhythms of change and firm performance. Acad. Manage. J. 56 (1), 160–184.
Leibenstein, H., 1966. Allocative efficiency vs." X-efficiency". Am. Econ. Rev. 56 (3), 392–415.
Leverty, J.T., Grace, M.F., 2010. The robustness of output measures in property-liability insurance efficiency studies. J. Banking Finance 34 (7), 1510–1524.
Lewellen, W.G., 1971. A pure financial rationale for the conglomerate merger. J. Finance 26 (2), 521–537.
Lonkevich, D., 1995. Pricing and consolidation: Farewell to the P/C cycle? Best's Rev. (Property-casualty insurance edition) 96 (5), 24.
Luhnen, M., 2009. Determinants of efficiency and productivity in German property-liability insurance: evidence for 1995–2006. Geneva Pap. Risk Insurance 34 (3), 483–505.
Ma, Y.L., Elango, B., 2008. When do international operations lead to improved performance? an analysis of property-liability insurers. Risk Manage. Insurance Rev. 11 (1), 141–155.
Mansfield, E., 1970. Micro-Economics. Norton, New York, NY.
McAllister, P.H., McManus, D., 1993. Resolving the scale efficiency puzzle in banking. J. Banking Finance 17 (2), 389–405.
Noulas, A.G., Ray, S.C., Miller, S.M., 1990. Returns to scale and input substitution for large US banks. J. Money, Credit Banking 22 (1), 94–108.
Outreville, J.F., 2012a. A note on geographical diversification and performance of the world's largest reinsurance groups. Multinational Bus. Rev. 20 (4), 376–391.
Outreville, J.F., 2012b. The world's largest reinsurance groups: a look at names, numbers and countries from 1980 to 2010. Insurance Risk Manage. 80 (1), 137–156.
Panzar, J.C., Willig, R.D., 1977. Economies of scale in multi-output production. Q. J. Econ. 91 (3), 481–493.
Panzar, J.C., Willig, R.D., 1981. Economies of scope. Am. Econ. Rev. 71 (2), 268–272.
Park, S.C., Xie, X., 2014. Reinsurance and systemic risk: the impact of reinsurer downgrading on property-casualty insurers. J. Risk Insurance 81 (3), 587–622.
Pasiouras, F., Gaganis, C., 2013. Regulations and soundness of insurance firms: international evidence. J. Bus. Res. 66 (5), 632–642.
Peltzman, S., 1977. The gains and losses from industrial concentration. J. Law Econ. 20 (2), 229–263.
Rhoades, S.A., 1985. Market share as a source of market power: implications and some evidence. J. Econ. Bus. 37 (4), 343–363.
Shephard, R.W., 1970. Theory of Cost and Production Functions, 4th ed. Princeton University Press, Princeton, NJ.
Simar, L., Wilson, P.W., 2000. A general methodology for bootstrapping in non-parametric frontier models. J. Appl. Stat. 27 (6), 779–802.
Simar, L., Wilson, P.W., 2007. Estimation and inference in two-stage, semi-parametric models of production processes. J. Econometrics 136 (1), 31–64.
Standard & Poor's Rating Services, 2003–2013. Global Reinsurance Highlights. McGraw Hill Financial, New York, NY.
Swiss Re. 2013. The essential guide to reinsurance http://www.swissre.com/rethinking/The_essential_guide_to_reinsurance.html
Teece, D.J., 1980. Economies of scope and the scope of the enterprise. J. Econ. Behav. Organiz. 1 (3), 223–247.
Upreti, V., Adams, M., 2015. The strategic role of reinsurance in the United Kingdom's (UK) non-life insurance market. J. Banking Finance 61, 206–219.
Weiss, L.W., 1974. The concentration-profits relationship and antitrust. In: Goldschmid, H.J., Mann, H. (Eds.), Industrial Concentration: The New Learning. Little. Brown, Boston, MA.
Weiss, M.A., Choi, B.P., 2008. State regulation and the structure, conduct, efficiency and performance of US auto insurers. J. Banking Finance 32 (1), 134–156.
Winter, R.A., 1994. The dynamics of competitive insurance markets. J. Financ. Intermediation 3 (4), 378–415.
Woodside, A.G., 2014. Embrace perform model: complexity theory, contrarian case analysis, and multiple realities. J. Bus. Res. 67 (12), 2495–2503.