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Frontier Efficiency Methodologies to Measure Performance in the Insurance Industry: Overview, Systematization, and Recent Developments

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The purpose of this paper is to provide an overview on frontier efficiency measurement in the insurance industry, a topic of great interest in the academic literature during the last several years. We provide a comprehensive survey of 95 studies with a special emphasis on innovations and recent developments. We review different econometric and mathematical programming approaches to efficiency measurement in insurance and discuss the choice of input and output factors. Furthermore, we categorise the 95 studies into 10 different areas of application and discuss selected results. While there is a broad consensus with regard to the choice of methodology and input factors, our review reveals large differences in output measurement. Significant need for future research can be identified, for example, with regard to analysis of organisational forms, market structure and risk management, especially in the international context.
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Introduction

Academics as well as practitioners in the insurance sector have spent significant resources in the last years to develop management techniques appropriate for the rapidly changing marketplace. New regulatory requirements, increasing competition, and the recent dynamics in capital markets have all fundamentally changed the business environment that insurers are active in. In such rapidly changing markets, shareholders and managers need accurate and reliable information about the value generated by their business activities. As a result most insurance companies have adopted modern management techniques such as shareholder value or value-based management. Benchmarking techniques can be used in a variety of ways to assist firms in evaluating whether they are performing better or worse than their peers in terms of technology, scale, cost minimisation, and revenue maximisation. They can be used to direct management efforts to the areas that need improvement, to identify attractive targets for mergers and acquisitions (M&A), and for many other purposes. Performance measurement can also be used within the firm to compare the performance of departments, divisions, branches, and agencies.

In this paper, we focus on a new class of benchmarking techniques called frontier efficiency methodologies. Frontier methodologies measure firm performance relative to "best practice" frontiers comprised of the leading firms in the industry. They are superior to traditional techniques such as financial ratio analysis because they summarise performance in a single statistic that controls for differences among firms using a sophisticated multidimensional framework (see Cummins and Weiss[1]).

Efficiency measurement is one of the most rapidly growing streams of literature and the insurance sector in particular has seen extreme growth in the number of studies applying frontier efficiency methods. Berger and Humphrey[2] and Cummins and Weiss[1] surveyed eight and 21 studies, respectively. Now, less than 10 years after the Cummins/Weiss survey, we find 95 studies on efficiency measurement in the insurance industry. Recent work in the field has refined methodologies, addressed new topics (e.g., market structure and risk management), and extended geographic coverage from a previously U.S.-focused view to a broad set of countries around the world, including emerging markets such as China and Taiwan.

The aim of this paper is to provide a comprehensive survey of these 95 studies on frontier efficiency measurement in insurance with a special emphasis on innovations and recent developments. We review different econometric and mathematical programming approaches to efficiency measurement in insurance and discuss the choice of input and output factors. Furthermore, we categorise the 95 studies into 10 different areas of application and discuss selected results.

Our four main results can be summarised as follows. (1) Data envelopment analysis (DEA) is the most frequently applied method of frontier efficiency analysis in insurance. In recent years, however, there have been many proposals for refining and further developing methodologies, for example, by applying more appropriate functional forms for the econometric approaches. (2) There is a widespread agreement with regard to the choice of input factors; most studies define, at a minimum, labour, capital, and business services (or an equivalent) as inputs of an insurance company. There is also agreement with regard to output measurement; most studies employ the so called value-added approach. However, there is disagreement among researchers as to whether premiums or claims are the more adequate proxy for value added. (3) There has been a recent expansion to new fields of application such as market structure and risk management. Also, geographic scope has noticeably expanded beyond its former U.S. focus to encompass a broad array of countries—45 according to our survey—including emerging markets such as China, Taiwan, and Malaysia. (4) Finally, we identify significant need for future research, for example, especially in the field of organisational form, market structure, risk management, and with regard to different lines of business. As most studies focus on U.S. insurance markets, significant research opportunities in international insurance markets are highlighted.

This paper contributes to the academic literature on frontier efficiency measurement for insurance in several ways: Apart from providing a comprehensive overview of this strongly growing body of literature, we conduct a systematisation of the different applications of frontier efficiency measurement in insurance. Moreover, we study recent innovations with regard to methodology and application and identify fields for future research. Thus, this paper serves as an overview for researchers in the field as

[1] Cummins and Weiss (2000).
[2] Berger and Humphrey (1997).

well as for regulators and managers interested in the results and implications of frontier efficiency studies.

The remainder of the paper is organised as follows. "Overview of efficiency measurement in the insurance industry" section starts with an overview of the 95 studies focusing on frontier efficiency in the insurance industry, subdivided in 10 application areas. The "Frontier efficiency methodologies" section introduces the two principal methodological approaches to efficiency measurement, surveys their implementation in insurance studies, and highlights recent innovations. The "Input and output factors used in efficiency measurement" section contains an overview on the usage of input and output factors. In the "Fields of application in efficiency measurement" section, we get back to 10 application areas and discuss the most important findings from the 95 studies. Finally, the "Conclusion and implications for future research" section concludes and highlights options for future research.

Overview of efficiency measurement in the insurance industry

The following overview of 95 papers (63 published articles, 32 working papers) builds upon and significantly extends two earlier surveys of efficiency measurement literature in the financial services industry: One by Berger and Humphrey,[2] which focuses on banks. The second one by Cummins and Weiss[1] focuses on the insurance industry and covers 21 studies that have been published until the year 1999. Three studies (Weiss;[3] Bernstein[4]) that are considered in Cummins and Weiss[1] have been excluded from this overview since they are not efficient frontier based, but focus on productivity (these studies are included in an extended overview that we present in the Appendix).

Table 1 is arranged according to 10 different application areas (first column). Some of these application areas have been selected following Berger and Humphrey's[2] overview for the banking sector. However, we extended and refined their systematisation to account for the specifics of the insurance sector. Although many studies make contributions to more than one topic, we tried to focus on the primary field of application. A more detailed table with information, such as input and output factors, types of efficiencies analysed, sample periods, lines of business covered, and main findings, is included in the Appendix.[5]

Frontier efficiency methodologies

Frontier efficiency methodologies measure the performance of a company relative to a "best practice" frontier, which (in the case of single input/output) is determined by the most efficient companies in the industry. The efficiency score is usually standardised between 0 and 1, with the most (least) efficient firm receiving the value of 1 (0). The difference between a company's assigned value and the value of 1 can be interpreted as

[3] Weiss (1986, 1991b).
[4] Bernstein (1999).
[5] In order to identify and summarize articles, we have specified a search strategy based on a list of relevant keywords, journals, databases, and authors. All details on the search strategy are available upon request.

Table 1 Studies on efficiency in the insurance industry

Application	*Country*	*Method*	*Author (date)*
Distribution systems	U.S.	DFA	Berger *et al*. (1997)
	U.S.	DEA	Brockett *et al*. (1998)
	U.S.	DEA	Carr *et al*. (1999)
	U.K.	SFA	Klumpes (2004)
	Germany	DEA	Trigo Gamarra and Growitsch (2008)
	U.K.	SFA	Ward (2002)
Financial and risk management, capital utilization	U.S.	DEA	Brockett *et al*. (2004a)
	U.S.	SFA	Cummins *et al*. (2006)
	U.S.	DEA	Cummins and Nini, 2002
General level of efficiency and evolution over time	Portugal	DEA	Barros *et al*. (2005)
	Nigeria	DEA	Barros and Obijiaku (2007)
	The Netherlands	SFA	Bikker and van Leuvensteijn (2008)
	U.S.	DEA	Cummins (1999)
	Tunisia	DEA, SFA	Chaffai and Ouertani (2002)
	Italy	DEA	Cummins *et al*. (1996)
	U.S.	SFA	Cummins and Weiss (1993)
	France	DEA, SFA	Fecher *et al*. (1993)
	U.S.	DFA	Gardner and Grace (1993)
	Taiwan	DFA	Hao (2007)
	Taiwan	DFA, SFA	Hao and Chou (2005)
	U.K.	SFA	Hardwick (1997)
	China	SFA	Huang (2007)
	Germany	DEA	Kessner and Polborn (1999)
	China	DEA	Leverty *et al*. (2004)
	Germany	DEA	Luhnen (2008)
	Malaysia	DEA	Mansor and Radam (2000)
	Greece	DEA	Noulas *et al*. (2001)
	China	DEA	Qiu and Chen (2006)
	India	DEA	Tone and Sahoo (2005)
	U.S.	SFA	Weiss (1991a)
	Australia	DEA	Worthington and Hurley (2002)
	China	DEA	Yao *et al*. (2007)
Intercountry comparisons	France, Belgium	DEA, SFA	Delhausse *et al*. (1995)
	6 European countries	DEA	Diacon (2001)
	15 European countries	DEA	Diacon *et al*. (2002)
	15 OECD countries	DEA	Donni and Fecher (1997)
	36 countries	DEA, SFA	Eling and Luhnen (2008)
	Germany, U.K.	DEA	Kessner (2001a)
	Austria, Germany	DEA	Mahlberg (1999)
	11 OECD countries	DFA, SFA	Rai (1996)
	18 European countries	SFA	Vencappa *et al*. (2008)
	14 European countries	SFA	Zanghieri (2008)
Market structure	U.S.	SFA	Choi and Weiss (2005)
	U.S.	SFA	Choi and Weiss (2008)
	14 European countries	SFA	Fenn *et al*. (2008)

Table 1 (*continued*)

Application	*Country*	*Method*	*Author (date)*
Mergers	U.S.	DEA	Cummins *et al.* (1999a)
	U.S.	DEA	Cummins and Xie (2008)
	7 European countries	DEA	Davutyan and Klumpes (2008)
	U.S.	DFA	Kim and Grace (1995)
	7 European countries	DEA	Klumpes (2007)
Methodology issues, comparing different techniques or assumptions	U.S.	DEA	Brockett *et al.* (2004b)
	U.S.	DEA, DFA, FDH, SFA	Cummins and Zi (1998)
	Spain	SFA	Fuentes *et al.* (2001)
	Japan	DEA	Fukuyama and Weber (2001)
	Taiwan	DEA	Hwang and Kao (2008a)
	Taiwan	DEA	Hwang and Kao (2008b)
	U.S.	DEA	Leverty and Grace (2008)
	Canada	DEA	Wu *et al.* (2007)
	Canada	DEA	Yang (2006)
Organisational form, corporate governance issues	U.S.	DEA	Brockett *et al.* (2005)
	Spain	DEA	Cummins *et al.* (2004)
	U.S.	DEA	Cummins *et al.* (1999b)
	Germany	DEA	Diboky and Ubl (2007)
	Belgium	FDH	Donni and Hamende (1993)
	U.S.	DEA	Erhemjamts and Leverty (2007)
	Japan	DEA	Fukuyama (1997)
	U.S.	SFA	Greene and Segal (2004)
	U.K.	DEA	Hardwick *et al.* (2004)
	Japan	DEA	Jeng and Lai (2005)
	U.S.	DEA	Jeng *et al.* (2007)
	Germany	DEA	Wende *et al.* (2008)
	U.S.	DEA	Xie (2008)
Regulation change	Ukraine	DEA	Badunenko *et al.* (2006)
	Korea, Philippines, Taiwan, Thailand	DEA	Boonyasai *et al.* (2002)
	Spain	DEA	Cummins and Rubio-Misas, 2006
	Austria	SFA	Ennsfellner *et al.* (2004)
	Germany, U.K.	DEA, DFA	Hussels and Ward (2006)
	Germany	DEA	Mahlberg (2000)
	Germany	DEA	Mahlberg and Url (2000)
	Austria	DEA	Mahlberg and Url (2003)
	Germany, U.K.	DEA	Rees *et al.* (1999)
	U.S.	DFA	Ryan and Schellhorn (2000)
	Germany	SFA	Trigo Gamarra (2008)
	Italy	DEA	Turchetti and Daraio (2004)
	U.S.	SFA	Yuan and Phillips (2008)
Scale and scope economies	U.S.	TFA, SFA	Berger *et al.* (2000)
	U.S.	DEA	Cummins *et al.* (2007)
	France	SFA	Fecher *et al.* (1991)
	Spain	SFA	Fuentes *et al.* (2005)
	Japan	SFA	Hirao and Inoue (2004)

Table 1 (*continued*)

Application	*Country*	*Method*	*Author (date)*
	Ireland	DFA	Hwang and Gao (2005)
	Germany	DEA	Kessner (2001b)
	U.S.	DFA	Meador *et al*. (2000)
	Finland	SFA	Toivanen (1997)
	U.S.	SFA, TFA	Yuengert (1993)

Abbreviations: DEA: Data envelopment analysis; DFA: Distribution-free approach; FDH: Free disposal hull; SFA: Stochastic frontier approach; TFA: Thick frontier approach.

the company's improvement potential in terms of efficiency (see, e.g., *Cooper et al.*[6]). Different types of efficient frontiers can be estimated. In the simplest case, a production frontier is estimated, assuming that companies minimise inputs conditional on given output levels (input-orientation) or maximise outputs conditional on given input levels (output-orientation).

There are two main approaches in efficient frontier analysis: the econometric approach and the mathematical programming approach. We shortly introduce these two approaches (including references to detailed overviews), discuss their application to the insurance field, and highlight recent innovations.[7]

Econometric approaches

The econometric approaches specify a production, cost, revenue, or profit function with a specific shape and make assumptions about the distributions of the inefficiency and error terms. There are three principal types of econometric frontier approaches. Although they all specify an efficient frontier form—usually translog, but also alternative forms such as generalised translog, Fourier flexible, or composite cost—they differ in their distributional assumptions of the inefficiency and random components (see Cummins and Weiss[1]). The *stochastic frontier approach* assumes a composed error model where inefficiencies follow an asymmetric distribution (e.g., half-normal, exponential, or gamma) and the random error term follows a symmetric distribution, usually normal. The *distribution-free approach* (DFA) makes fewer specific assumptions, but requires several years of data. Efficiency of each company is assumed to be stable over time, and the random noise averages out to zero. Finally, the *thick frontier approach* does not make any distributional assumptions for the random error and inefficiency terms, but assumes that inefficiencies differ between the highest and lowest quartile firms (see, e.g., Kumbhakar and Lovell[8]).

[6] Cooper *et al*. (2007).
[7] Due to space constraints we restrict ourselves to a basic description of the methodologies and focus on recent developments and applications in the insurance industry. An extended version of this paper that contains more details on the different methodologies is available upon request.
[8] Kumbhakar and Lovell (2000).

The most commonly used econometric approach is *stochastic frontier analysis* (SFA), which was first proposed by Aigner *et al.*[9] SFA is usually applied in two steps: In the first step, a production, cost, revenue, or profit function is estimated, determining the efficient frontier. In the second step, for individual firms, deviations from the efficient frontier due to inefficiency and a random error are calculated (see Cummins and Weiss[1]). To illustrate SFA formally, we use a translog cost function that has been widely used in literature and shown to approximate the form of the real underlying cost function fairly well (see, e.g., Rai;[10] Cummins and Zi;[11] Cummins and Weiss;[1] Choi and Weiss[12]):

$$\ln C_i = \ln \hat{C}(p_i, y_i) + \varepsilon_i, \tag{1}$$

where C_i are total observed costs of insurer *i*. $1\text{n}\hat{C}(p_i, y_i)$, the log cost function that needs to be estimated contains a vector of input prices p_i and a vector of output quantities y_i. The error term ε_i shows how far an insurer is from the efficient frontier. The deviation might be due to two reasons and these are modelled as $\varepsilon_I = u_i + v_i$. The first reason, modelled by the first term (u_i) are random deviations from the efficient frontier; usually, u_i is assumed to be standard normally distributed. The second reason (modelled by the term v_i) is inefficiency, which is usually assumed to be half-normally distributed. To estimate efficiency, $1\text{n}\hat{C}(p_i, y_i)$ is calculated using an econometric method, such as ordinary least squares or maximum likelihood. Then the residual is computed as:

$$\ln C_i - \ln \hat{C}(p_i, y_i) = \varepsilon_i, \tag{2}$$

where ε_i needs to be broken down into the components u_i and v_i. This is done by finding the conditional probability distribution of v_i given ε_i. Cost efficiency is then calculated as:

$$Efficiency_{it} = \frac{E(C_i | v_i = 0, G_i)}{E(C_i | v_i, G_i)}, \tag{3}$$

where C_i are total observed costs of insurer *i* and G_i is a vector of input prices and output quantities of insurer *i*. The numerator of Eq. (3) reflects minimum cost achievable, provided output and technology, if the insurer *i* operates at full efficiency (i.e. v_i=0). The denominator shows actual costs of insurer *i* given the actual level of efficiency.

There are two configuration decisions that must be made when employing SFA: (1) The choice of the functional form to approximate the real underlying production, cost, revenue, or profit function; and (2) the distributional assumption for the inefficiency term. The translog is an accepted and widely used functional form, but there are a variety of other options, including the Cobb-Douglas, Fuss normalised quadratic (see

[9] Aigner *et al.* (1979).
[10] Rai (1996).
[11] Cummins and Zi (1998).
[12] Choi and Weiss (2005).

Morrison and Berndt[13]), and generalised translog (see Caves *et al.*[14]). The composite cost (see Pulley and Braunstein[15]) or the Fourier flexible form (see Gallant[16]) have also been applied in the financial services industry. While the random error term is usually assumed to be distributed normally, the inefficiency term has been specified to have different distributions, such as half-normal, truncated normal, exponential, or gamma (see, e.g., Berger and Humphrey[2]).

Mathematical programming approaches

Compared with the econometric approaches, the mathematical programming approaches put significantly less structure on the specification of the efficient frontier and do not decompose the inefficiency and error terms. The most widespread mathematical programming approach is "DEA", which uses linear programming to measure the relationship of produced goods and services (outputs) to assigned resources (inputs). DEA determines the efficiency score as an optimisation result. DEA models can be specified under the assumption of constant returns to scale (CRS) or variable returns to scale (VRS) and can be used to decompose cost efficiency into its single components—technical, pure technical, allocative, and scale efficiency. To illustrate DEA, we discuss a basic model for measuring technical efficiency assuming CRS (see, e.g., Cummins and Nini;[17] Worthington and Hurley;[18] Cooper *et al.*[6]). Efficiency e of an insurer i is measured by the ratio:

$$e_i = \frac{s_i^T y_i}{r_i^T x_i}, \tag{4}$$

where y_i is a vector with outputs, $j{=}y_{j,i}{=}1, \ldots, z$, of firm i. x_i is a vector with inputs $x_{k,i}$, $k{=}1, \ldots, w$. S_i^T is the transposed vector of output weights and r_i^T the transposed vector of input weights. Input and output data are assumed to be positive. For each insurer i, the following optimisation problem must be solved in order to obtain optimal input and output weights for the maximisation of efficiency:

$$\begin{aligned} &\max_{s,r} e_i = \frac{s_i^T y_i}{r_i^T x_i}, \text{subject to :} \\ &\frac{s_i^T y_i}{r_i^T x_i} \leqslant 1 \\ &s_{j,i}, r_{k,i} 0,\ \forall j = 1, \ldots, z, k = 1, \ldots, w. \end{aligned} \tag{5}$$

[13] Morrison and Berndt (1982).
[14] Caves *et al.* (1980).
[15] Pulley and Braunstein (1992).
[16] Gallant (1982).
[17] Cummins and Nini (2002).
[18] Worthington and Hurley (2002).

The first condition of Eq. (5) limits the ratio e_i of weighted outputs to weighted inputs to a maximum of 1. Since the fractional program (Eq. (5)) has an infinite number of solutions, it must be transformed into a linear programme by imposing the constraint $r_i^T x_i$=1, implying that the weighted sum of inputs is standardised to 1:

$$\begin{aligned} &\max_{s,r} e_i = s_i^T y_i, \text{subject to :} \\ &r_i^T x_i = 1 \\ &s_i^T y_i - r_i^T x_i \leqslant 0 \\ &s_{j,i}, r_{k,i} 0,\ \forall j = 1, \ldots, z, k = 1, \ldots, w. \end{aligned} \qquad (6)$$

The *free-disposal hull* (FDH) approach is a special configuration of DEA. Under this approach, the points on the lines connecting the DEA vertices are excluded from the frontier and the convexity assumption on the efficient frontier is relaxed (see Cooper *et al.*[6]).

Total Factor Productivity

The concept of *total factor productivity* is closely related to efficiency and often used in efficiency studies. Productivity is an index that relates the total amount of outputs produced to the total amount of inputs used in the production process (see Cummins and Weiss (p. 770)). Total factor productivity growth is thus measured as the change in total outputs net of the change in total input usage. In contrast, the concept of efficiency measures inputs and outputs in relation to a benchmark, that is, the optimal input-output usage in an industry. Of special interest is the *Malmquist index of total factor productivity*, since many of the reviewed studies work with this measure in combination with DEA analysis (see, e.g., Cummins *et al.*;[19] Cummins and Rubio-Misas[20]). The important feature of the Malmquist index is that it is able to decompose total factor productivity growth into two elements: Technical efficiency changes to determine how much the distance of an individual firm to the efficient frontier has changed, and technical change to determine the movements of the efficient frontier itself due to technical change over time (see Grosskopf;[21] Cummins and Weiss[1]). Overall, the total factor productivity growth is relatively lower in the insurance industry, especially compared to manufacturing industries (Bernstein;[4] Fuentes *et al.*;[22] Luhnen[23]).

Comparison and discussion of recent developments

Both the econometric and mathematical programming approaches have their advantages and disadvantages and there is no consensus as to which method is

[19] Cummins *et al.* (1999b).
[20] Cummins and Rubio-Misas (2006).
[21] Grosskopf (1993)
[22] Fuentes *et al.* (2001).
[23] Luhnen (2008).

superior (see, e.g., Cummins and Zi;[11] Hussels and Ward[24]). The econometric approach has the main disadvantage of using strong assumptions regarding the form of the efficient frontier. It assumes a specific functional form, such as the translog or composite cost, and therefore expects a certain underlying economic behaviour, which may not be valid. The mathematical programming approach thus has the advantage of imposing less structure on the efficient frontier. However, compared to the econometric approach, it has the disadvantage of not taking into account a random error term. Consequently, mathematical programming approaches run the risk of taking all deviations from the efficient frontier as inefficiencies, therefore possibly mistaking a true random error for inefficiency (see Berger and Humphrey[2]).

In empirical studies, the DEA approach has been most frequently used. Out of the 95 surveyed studies, 55 use DEA, 22 SFA, seven DFA, and one FDH. Ten studies follow the advice given by Cummins and Zi[11] and consider multiple approaches, ideally from both the econometric and mathematical programming sides. Most of these find highly correlated results when ranking firms by their relative efficiency according to different approaches (see, e.g., Hussels and Ward[24]). However, both approaches illuminate efficiency from different perspectives and thus deliver different insights. This is why we follow Cummins and Zi[11] and recommend considering both DEA and SFA in empirical studies. Given significant increases in computer power and availability of software for both these approaches makes a combined analysis feasible and the interpretation of the empirical findings much richer.

For DEA, the most widely used specifications have been under the assumption of VRS. For SFA, most studies chose the translog functional form. Total factor productivity has been calculated by 24 studies—in combination with DEA in 21 cases and with SFA in three cases. The choice of methods is often determined by the available data. For example, if the available data are known to be noisy, the econometric approach, featuring an error term to accommodate noise, may lead to more accurate results. In this case, the mathematical programming approach would not be appropriate, since it mistakes the noise as inefficiencies due to the fact that there is no error term (see Cummins and Weiss[1]).

In recent years, there have been a number of proposals for the improvement of efficiency measurement in the field of insurance. For the *econometric approach*, a major direction has been to apply more flexible specifications of the functional form. Examples are the composite cost function or the Fourier flexible distribution (see, e.g., Fenn *et al.*[25]). Also, Bayesian stochastic frontier models (see Van den Broeck *et al.*[26]), featuring advantages, such as exact small-sample inference on efficiencies, have been applied (see, e.g., Ennsfellner *et al.*[27]). A further proposal has been made regarding the incorporation of firm-specific variables into the estimation process. Instead of using a two-stage approach, which first estimates inefficiency of sample firms and then examines the association of inefficiency with firm-specific variables through

[24] Hussels and Ward (2006).
[25] Fenn *et al.* (2008).
[26] Van den Broeck *et al.* (1994).
[27] Ennsfellner *et al.* (2004).

regressions, a one-stage approach is suggested. In this approach, the estimated frontier directly takes into account firm-specific variables by modelling mean inefficiency as a function of firm-specific variables (conditional mean approach, see, e.g., Huang and Liu;[28] Greene and Segal[29]). Fenn *et al.*[25] address the drawback of the conditional mean approach, that the variance of the random and efficiency errors is assumed constant. Following a procedure by Kumbhakar and Lovell,[8] they explicitly model the variance of both types of errors and thus correct for potential heteroscedasticity.

Another contribution has been made with regard to the Malmquist index of total factor productivity. Although this index is usually applied to non-parametric DEA for insurance companies, Fuentes *et al.*[22] develop a parametric distance function that enables them to calculate the Malmquist index also for the econometric approach. They show that using the estimated regression parameters, several radial distance functions can be calculated and combined in order to estimate and decompose the productivity index.

A drawback of the *mathematical programming approach* has been the lack of statistical properties. But Banker[30] has shown that DEA estimators can also be interpreted as maximum likelihood estimators under certain conditions, providing a statistical base to DEA. However, the sampling distribution of the underlying DEA efficiency estimators stays unknown (see, e.g., Berger and Humphrey[2]). Also, DEA efficiency estimates have been shown to be biased upward in finite examples (see, e.g., Simar and Wilson[31]). In this context, the bootstrapping procedure proposed by Simar and Wilson[31] has been applied to the insurance industry. It provides an empirical approximation of the sampling distribution of efficiency estimates and corrects the upwards bias (see, e.g., Cummins *et al.*;[32] Diboky and Ubl;[33] Erhemjamts and Leverty[34]). Simar and Wilson[35] also introduce a truncated regression and bootstrapping procedure that allows to investigate the impact of external variables on efficiency scores permitting valid inference, as opposed to the commonly used Tobit regression approaches.

A further innovation is the introduction of cross-frontier efficiency analysis, which estimates efficiency of firms using one particular technology relative to the best practice frontier of firms using an alternative technology. Cross-frontier efficiency analysis makes it possible to determine whether the outputs of one specific technology could be produced more efficiently by using the alternative technology. Cross-frontier analysis has been used to examine the efficiency of different organisational forms, comparing technical, cost, and revenue efficiency of stocks and mutual insurers (see Cummins *et al.*[36]). It has also been used for the analysis of scope economies,

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28 Huang and Liu (1994).
29 Greene and Segal (2004).
30 Banker (1993).
31 Simar and Wilson (1998).
32 Cummins *et al.* (2007).
33 Diboky and Ubl (2007).
34 Erhemjamts and Leverty (2007).
35 Simar and Wilson (2007).
36 Cummins *et al.* (1999b, 2003, 2004).

comparing diversified and specialist firms (see Cummins *et al.*[32]). Finally, Brocket *et al.*[37] apply a range-adjusted measure version of DEA to the insurance industry. This DEA version, in contrast to other DEA models, offers the advantage of being able to produce efficiency rankings suitable for significance tests such as the Mann-Whitney statistic.

Input and output factors used in efficiency measurement

Choice of input factors

There are three main insurance inputs: *labour*, *business services and materials*, and *capital*. Labour can be further divided into agent and home-office labour. The category of business services and materials is usually not further subdivided, but includes items like travel, communications, and advertising. At least three categories of capital can be distinguished: physical, debt, and equity capital (see Cummins *et al.*;[38] Cummins and Weiss[1]). Data on the number of employees or hours worked are not publicly available for the insurance industry in most cases. Therefore, in order to proxy labour and business service input, input quantities are derived by dividing the expenditures for these inputs with publicly available wage variables or price indices. For example, the U.S. Department of Labour data on average weekly wages for SIC Class 6,311 (home-office life insurance labour), can be used in the case of studying the U.S. insurance industry (see, e.g., Berger *et al.*;[39] Cummins and Zi[11]). Physical capital is often included in the business service and materials category, but debt and equity capital are important inputs for which adequate cost measures have to be found (see, e.g., Cummins *et al.*[19]).

Sixty-one out of 95 studies use at least labour and capital as inputs and most of them also add a third category (miscellaneous, mostly business services). Out of those 61 studies, 18 differentiate between agent and non-agent labour. Also, the number of studies differentiating between equity and debt capital is low; only 16 do so. Regarding the 34 contributions that do not employ the standard input categories, 21 of them incorporate broader expenditure categories as inputs—for example, total operating expenses—without decomposing them into quantities and prices (see, e.g., Rees *et al.*;[40] Mahlberg and Url[41]). Nine studies do not cover capital explicitly, that is, they consider labour only or labour and an additional composite category. Finally, four studies that focus on financial intermediation consider only capital-related inputs (see, e.g., Brocket *et al.*[42]). The choice of input prices is mainly determined by the data that are publicly available in the countries under investigation.

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[37] Brocket *et al.* (2005).
[38] Cummins *et al.* (1999a).
[39] Berger *et al.* (1997).
[40] Rees *et al.* (1999).
[41] Mahlberg and Url (2003).
[42] Brocket *et al.* (1998).

Choice of output factors

There are three principal approaches to measure outputs. The *intermediation approach* views the insurance company as a financial intermediary that manages a reservoir of assets, borrowing funds from policy-holders, investing them on capital markets, and paying out claims, taxes, and costs (see Brocket *et al.*;[42] also called flow approach; see Leverty and Grace[43]). The *user-cost method* differentiates between inputs and outputs, based on the net contribution to revenues. If a financial product yields a return that exceeds the opportunity cost of funds or if the financial costs of a liability are less than the opportunity costs, it is deemed a financial input. Otherwise, it is considered a financial output (see Hancock;[44] Cummins and Weiss[1]). The *value-added approach* (also called production approach; see Grace and Timme;[45] Berger *et al.*[46]) counts outputs as important if they contribute a significant added value, based on operating cost allocations (see Berger *et al.*[46]). Usually, several types of outputs are defined, representing the single lines of business under review.

The value-added approach assumes that the insurer provides three main services, for which volume output proxies must be defined: Through the first service, risk-pooling and risk-bearing, insurers create value added by operating a risk pool, collecting premiums from policy-holders, and redistributing most of them to customers who have incurred losses. Via the second service, "real" financial services relating to insured losses, insurers create added value for their policy-holders by providing real services such as financial planning (life) or the design of coverage programs (property-liability). The third service is intermediation; insurers create added value by acting as financial intermediaries that invest the premiums provided by the policy-holders, for example, on the capital market and pays out claims and administrative expenses (see, e.g., Cummins and Nini[17]).

To proxy the risk-pooling/risk-bearing function, either premiums or incurred benefits (life) and present value of losses (property-liability) have been used. Different output proxies are thus used for life and property-liability insurers, reflecting differences in the types of insurance and data availability (see Berger *et al.*[39]). In literature, there is an intense debate as to whether premiums are an appropriate proxy because they represent price times quantity of output and not output (see, e.g., Yuengert[47]). The present value of real losses incurred, however, can be used as a reasonable proxy for output as it corresponds closely to the theoretical measures used in insurance economics (see Cummins and Weiss,[1] for a theoretical derivation based on the Pratt-Arrow concept of the insurance premium). The risk-pooling/risk-bearing function involves collecting funds from everyone in the risk pool and redistributing it to policy-holders that incur losses. Thus, losses represent the total amount redistributed by the pool and are a useful risk proxy (see Berger *et al.*[39]). In life insurance, incurred benefits represent payments received by policy-holders in the current year;

[43] Leverty and Grace (2008).
[44] Hancock (1985).
[45] Grace and Timme (1992).
[46] Berger *et al.* (2000).
[47] Yuengert (1993).

they measure the amount of funds pooled by insurers and redistributed to policy-holders as compensation for insured events and are thus comparable to the loss proxy in property-liability insurance. Insurers issue debt contracts (insurance policies and annuities) and invest the funds until they are withdrawn by policy-holders (in the case of asset accumulation products sold by life insurers) or are needed to pay claims (see Cummins and Weiss[1]). Additions to reserves or invested assets are thus good proxies for the intermediation function and often used in literature (see, e.g., Cummins *et al.*;[19] Berger *et al.*[39]). Both incurred benefits/present value of losses, as well as additions to reserves/invested assets, are correlated with the third function, real financial services of the insurer.

Comparison and discussion of recent developments

The value-added approach has been established as best practice; 80 out of 95 studies apply this approach (see Appendix). However, there is a debate among those using the value-added approach as to whether claims/benefits or premiums/sum insured are the most appropriate proxy for value added. Out of the 80 articles, 46 follow Cummins and Weiss[1] and specify output as either claims/present value of claims (property-liability) or benefits/net incurred benefits (life). 32 studies specify output as premiums/sum insured. Two studies use both proxies—claims for non-life and premiums for life insurance. One study uses neither of the two main proxies: Yuengert[47] takes reserves/additions to reserves as a proxy for value added. Although more studies use claims/benefits to proxy output than premiums/sum insured, there is no recognisable trend over time as to whether either of the two main proxies is gaining more of a following among researchers.[48]

Since the value-added approach to output measurement dominates the literature, there have only been few innovations with regard to output measurement. Hwang and Kao[49] introduce a new relational two-stage production process, in which the outputs of the first production stage, called "premium acquisition", are the inputs for the second production stage, called "profit generation". Regarding the other two approaches for output measurement, five studies employ the intermediation approach, for example, taking return on investment (ROI), liquid assets to liability, and solvency scores as outputs (see Brocket *et al.*[50]).

A reflection of popularity is not necessarily an indication of validity. A good example is the controversial discussion in literature on value added vs. financial intermediation approaches (Brocket *et al.*;[51] Leverty and Grace[43]). Cummins and Weiss[1] argues that the financial intermediation approach is not optimal because insurers provide many services in addition to financial intermediation. Leverty and

[48] We categorized the number of studies by usage of output proxy and year of publication: from 1991 to 1995, three studies use claims/benefits and five use premiums/sum insured; 1996–2000: 12/7; 2001–2005: 12/12; 2006–2008: 15/7. Premiums/sum insured might be used in many studies because these measures are more readily available for most countries.

[49] Hwang and Kao (2008a, b).

[50] Brocket *et al.* (2004a, b, 2005).

[51] Brocket *et al.* (2005).

Grace[43] show that the value-added approach is consistent with traditional measures of firm performance and inversely related to insurer insolvency. The intermediation approach is only weakly related to traditional performance measures and firms recognised as highly efficient have a higher probability to fail. In the light of these results it seems quite reasonable to prefer the value-added approach over the financial intermediation approach.

None of the studies reviewed uses the user-cost approach, because this approach requires precise data on product revenues and opportunity costs, which are not available in the insurance industry (see Klumpes[52]). Five studies use both the value-added and intermediation approaches (see, e.g., Jeng and Lai;[53] Leverty and Grace[43]). Two studies apply physical outputs, for example, Toivanen[54] uses number of product units produced as insurance output.

Fields of application in efficiency measurement

Frontier efficiency methods have been applied to a wide range of countries as well as to all major lines of business. Furthermore, frontier efficiency methods have been used to investigate various economic questions. These include risk management, market structure, organisational forms, and mergers. However, it should be noted that findings regarding the same economic issues often vary depending on country, line of business, time horizon, and method considered in the different studies. In the following, we analyse the 95 studies of our survey according to their field of application and selected main results. For this purpose, we consider ten application categories (see Table 1). As a quick overview, Table 2 summarises the main findings that are discussed in more detail below.

Distribution systems

Two main hypotheses have been developed to explain the coexistence of distribution systems in the insurance industry (see Berger *et al.*[39]). According to the *market-imperfections hypothesis,* independent-agency insurers survive while providing essentially the same services as direct-writing insurers because of market imperfections, such as, for example, price regulation or search costs. In contrast, according to the *product-quality hypothesis,* the higher costs of independent-agency insurers can be justified with higher product quality or greater service intensity, for example, by providing additional customer assistance with claims settlement or offering a greater variety of product choices.

While these two hypotheses argue in favour of coexistence, the empirical evidence is mixed. Brockett *et al.*,[55] studying the U.S., and Klumpes,[56] studying the U.K., find

[52] Klumpes (2007).
[53] Jeng and Lai (2005).
[54] Toivanen (1997).
[55] Brockett *et al.* (1998, 2004a).
[56] Klumpes (2004).

Table 2 Main findings from the 95 studies

Application	*Findings*
Distribution systems	• In most studies, independent agent distribution systems are more efficient than direct systems (Brockett *et al*. (1998, 2004a, b); Klumpes, 2004) • Insurers with one distribution system are more efficient than those employing more than one (Ward, 2002)
Financial and risk management, capital utilisation	• Risk management and financial intermediation increase efficiency (Cummins *et al*., 2006) • Solvency scores have limited impact on efficiency (Brockett *et al*., 2004a, b)
General level of efficiency and evolution over time	• Significant levels of inefficiency with corresponding room for improvement, for example, for Nigeria, Tunisia, Malaysia
Intercountry comparisons	• Striking international differences in average efficiency, for example, Nigeria (see Barros and Obijiaku, 2007), Tunisia (see Chaffai and Ouertani, 2002), Malaysia (see Mansor and Radam, 2000), or Australia (see Worthington and Hurley, 2002) • Efficiency in developed countries is on average higher than that in emerging markets and technical progress has increased productivity and efficiency around the world (Eling and Luhnen, 2008)
Market structure	• More efficient firms charge lower prices than their competitors (Choi and Weiss, 2005) • Larger firms with high market shares tend to be less cost efficient (Fenn *et al*., 2008)
Mergers	• Mergers are beneficial for the efficiency of acquiring and target firm (Cummins *et al*. (1999a); Cummins and Xie (2008) • Mergers and acquisitions, facilitated by the liberalised EU market, have led to efficiency gains (Fenn *et al*., 2008)
Methodology issues, comparing different techniques or assumptions	• Average efficiencies can differ significantly across methods (Cummins and Zi, 1998) • The value-added and intermediation approaches to efficiency measurement are not consistent (Leverty and Grace, 2008)
Organisational form, corporate governance issues	• Most authors find that stock companies are more efficient than mutuals (Cummins *et al*., 1999a) • Efficiency improvements after demutualisation were identified (Jeng *et al*., 2007)
Regulation change	• Modest efficiency improvements from deregulation in Europe (Rees *et al*., 1999; Hussels and Ward, 2006) • Efficiency gains in Asia due to deregulation (Boonyasai *et al*., 2002) • No efficiency change with risk-based capital requirements implementation in the U.S. (Ryan and Schellhorn (2000))
Scale and scope economies	• Increasing returns to scale for U.S. firms with up to US$1 billion in assets (Cummins and Zi, 1998) • Mostly evidence for economies of scope, more recently mixed evidence (Cummins *et al*., 2007)

that independent agent distribution systems are more efficient than direct systems involving company representatives or employed agents. Against it, Berger *et al.*[39] find for the U.S. that independent agent systems are less cost efficient, but equally profit efficient. On a more general level, Ward[57] finds for the U.K. that insurers focusing on one distribution system are more efficient than those employing more than one mode of distribution. Trigo Gamarra and Growitsch,[58] in a study for German life insurance, finds that single line insurers are neither more cost nor more profit efficient than multichannel insurers.

Financial and risk management, capital utilisation

Cummins *et al.*[59] were the first to explicitly investigate the relationship between risk management, financial intermediation, and economic efficiency. In their application to the U.S. property-liability industry, they analyse whether both activities contribute to efficiency through reducing costs of providing insurance. In order to show the contribution of risk management and financial intermediation to efficiency, they estimate shadow prices of these two activities. They find positive shadow prices of both activities and conclude that they significantly contribute to increasing efficiency. Brockett *et al.*[60] argue that solvency is a primary concern for regulators of insurance companies; they thus use solvency scores determined by a neural network model as outputs in efficiency measurement, but they find that these scores only have limited impact on efficiency in the U.S. property-liability market. Cummins and Nini[17] find for the same country and line of business, that large increases in capitalisation between 1989 and 1999 represent an inefficiency insofar as equity capital is significantly over-utilised.

General level of efficiency and evolution over time

This category contains a large number of studies that represent a first application of efficiency frontier methods to a country. Examples are Nigeria (see Barros and Obijiaku[61]), Tunisia (see Chaffai and Ouertani[62]), Malaysia (see Mansor and Radam[63]), or Australia (see Worthington and Hurley[64]). Given the broad range of countries and time horizons employed, findings regarding efficiency and productivity are mixed. However, nearly all studies note that there are significant levels of inefficiency with corresponding room for improvement. For example the Netherlands

[57] Ward (2002).
[58] Trigo Gamarra and Growitsch (2008).
[59] Cummins *et al.* (2006).
[60] Brockett *et al.* (2004a, b).
[61] Barros and Obijiaku (2007).
[62] Chaffai and Ouertani (2002).
[63] Mansor and Radam (2000).
[64] Worthington and Hurley (2002).

with 75 per cent cost efficiency on average have significant improvement potential (see Bikker and van Leuvensteijn[65]). The same is true for China with average technical efficiency of 77 per cent in non-life and 70 per cent in life (see Yao *et al.*[66]), as well as Greece with average cost efficiency of 65 per cent (see Noulas *et al.*[67]).

Intercountry comparisons

The first cross-country comparison was conducted by Weiss.[68] It covers the U.S., Germany, France, Switzerland, and Japan. She finds high productivity for the U.S. and Germany. Japan shows the weakest productivity growth for the period 1975–1987. Rai,[10] in a broader cross-country study (11 OECD countries), concludes that firms in Finland and France have the highest efficiency and firms in the U.K. have the lowest. Donni and Fecher[69] show for a sample of 15 OECD countries for the period 1983–1991 that average efficiency levels are relatively high, but vary across countries. Growth in productivity is observed for all countries, which is attributed to improvements in technical progress.

The introduction of the single European Union (EU) insurance license in 1994 raised concerns over international competitiveness among EU insurers. Consequently, there have been quite a few efficiency studies that focus on competition in the EU. For a sample of 450 companies from 15 European countries and for the period 1996–1999, Diacon *et al.*[70] find striking international differences in average efficiency. According to their study, insurers doing long-term business in the U.K., Spain, Sweden, and Denmark have the highest levels of technical efficiency. However, U.K. insurers seem to have particularly low levels of scale and allocative efficiency compared to the other European countries in the sample. Interestingly, and in contrast to the literature finding increasing levels of efficiency over time, these authors find decreasing technical efficiency.

Boonyasai *et al.*[71] study efficiency and productivity in Asian insurance markets. Their results show increasing productivity in Korea and Philippines due to deregulation and liberalisation, but liberalisation had little effect on productivity in Taiwan and Thailand. The most recent stream of efficiency literature, however, again focuses on EU markets and includes Klumpes[52] and Fenn *et al.*[72] Fenn *et al.*[72] find increasing returns to scale for the majority of EU insurers. The results indicate that mergers and acquisitions, facilitated by liberalised EU markets, have led to efficiency gains. Eling and Luhnen[73] combine the AM Best U.S. and Non-U.S. database and

[65] Bikker and van Leuvensteijn (forthcoming).
[66] Yao *et al.* (2007).
[67] Noulas *et al.* (2001).
[68] Weiss (1991 b).
[69] Donni and Fecher (1997).
[70] Diacon *et al.* (2002).
[71] Boonyasai *et al.* (2002).
[72] Fenn *et al.* (2008).
[73] Eling and Luhnen (2008).

conduct a cross-country comparison of insurers from 36 countries, 12 of which have not previously been analysed in literature.

Overall, the empirical evidence is consistent in finding that efficiency in developed countries is higher than that in emerging markets and that technical progress has increased productivity and efficiency around the world. However, again the empirical findings are not unambiguous. An example is the U.K., where many studies have consistently indicated relatively low efficiency levels compared to other countries (around 60 per cent; see Rai;[10] Fenn *et al.*;[72] Vencappa *et al.*[74]). Diacon,[75] however, finds higher efficiency for the U.K.—77 per cent, which is higher than that found for competing European countries in their study. Given that most efficiency research so far focuses on the U.S., significant need for research at the international level can be identified. With variations in market environments and cultural norms, we expect that future research will identify substantial differences in the results for the U.S. and for other insurance markets, for example, considering the effect of different organisational forms on efficiency or considering economies of scale and scope.

Market structure

Choi and Weiss[76] analyse three hypotheses derived from the industrial organisation literature: (1) The structure-conduct-performance hypothesis predicts that increased market concentration leads to higher prices and profits through increased possibilities for collusion among firms; (2) the relative market power (RMP) hypothesis focuses on economic rents and predicts that firms with relatively large market shares will exercise their market power and charge higher prices; (3) the efficient structure (ES) hypothesis claims that more efficient firms charge lower prices than their competitors, allowing them to capture larger market shares as well as economic rents, leading to increased market concentration. Choi and Weiss[12] confirm the ES hypothesis and suggest that regulators should be more concerned with efficiency rather than market power arising from industry consolidation. Results of Choi and Weiss[77] support the RMP hypothesis, implying that insurers in competitive and non-stringently regulated U.S. states could profit from market power and charge higher unit prices. However, firms in those states have been found, on average, more cost efficient, and cost efficient insurers charge lower prices, earning smaller profits. A further contribution to the topic of market structure with a focus on the EU has been made by Fenn *et al.*,[72] finding that larger firms with high market shares tend to be less cost efficient.

Mergers

Kim and Grace[78] conduct a simulation analysis of efficiency gains from hypothetical horizontal mergers in the U.S. life insurance industry. Their results indicate that most

[74] Vencappa *et al.* (2008).
[75] Diacon (2001).
[76] Choi and Weiss (2005, 2008).
[77] Choi and Weiss (2008).
[78] Kim and Grace (1995).

mergers would improve cost efficiencies, with the exception of mergers between large firms. Two other U.S. studies (Cummins *et al.*[79] for life insurance and Cummins and Xie[80] for property-liability insurance) conclude that mergers are beneficial for the efficiency of acquiring and target firm. Klumpes[52] tests the same hypothesis as Cummins *et al.*[38] and Cummins and Xie[80] for the European insurance market, and finds that acquiring firms are more likely to be efficient than non-acquiring firms. However, he finds no evidence that target firms achieve greater efficiency gains than non-target firms. Merger activity in the European insurance markets seems to be mainly driven by solvency objectives—that is, financially weak insurers are bought by financially sound companies—and less by value maximisation, as in the U.S.

Methodology issues, comparing different techniques or assumptions

A few studies primarily solve methodological issues or compare different techniques and assumptions over time. Cummins and Zi[11] compare different frontier efficiency methods—DEA, DFA, FDH, SFA—and find that the efficiency results can differ significantly across these methods. Fuentes *et al.*[22] introduce a parametric frontier approach for the application of the Malmquist index that has before that date only been used with non-parametric frontier approaches. Leverty and Grace[43] compare the value-added and intermediation approaches to efficiency measurement and find that these approaches are not consistent (see 'Econometric approaches'' and ''Mathematical programming approaches'' sections for more details on methodology and techniques).

Organisational form, corporate governance issues

A well-developed field of frontier efficiency analysis deals with the effect of organisational form on performance. The two principal hypotheses in this area are the expense preference hypothesis (see Mester[81]) and the managerial discretion hypothesis (see Mayers and Smith[82]). The expense preference hypothesis states that mutual insurers are less efficient than stock companies due to unresolved agency conflicts (e.g., higher perquisite consumption of mutual managers). The managerial discretion hypothesis claims that the two organisational forms use different technologies and that mutual companies are more efficient in lines of business with relatively low managerial discretion (see Cummins and Weiss[1]).[83]

The empirical evidence on these two hypotheses has been mixed. Most studies find that stock insurers are more efficient than mutuals, confirming the expense preference

[79] Cummins *et al.* (1999a).
[80] Cummins and Xie (2008).
[81] Mester (1991).
[82] Mayers and Smith (1988).
[83] The hypothesis that stocks and mutuals use different technologies is also called efficient structure hypothesis (Cummins *et al.*, 2004; Wende *et al.*, 2008), but this hypothesis is not related to the efficient structure hypothesis mentioned with the discussion of market structure in 'Market structure'' section.

hypothesis (see, e.g., Cummins *et al.*[38] and Erhemjamts and Leverty[84] for the U.S. market; Diboky and Ubl[3] for Germany). However, other studies have found mutuals more efficient than stocks. For example, Diacon *et al.*,[70] in a comparison of 15 European countries, find higher levels of technical efficiency for mutuals than for stocks. Also, Greene and Segal[85] in an application to the U.S. life insurance industry, suggest that mutual companies are as cost efficient as stock companies. Other studies investigate efficiency improvements after demutualisation (see, e.g., Jeng *et al.*[86]) and compare the efficiency of firms after initial public offerings vs. that of private firms (see Xie[87]). Looking at corporate governance issues, a positive relation between cost efficiency and the size of the corporate board of directors was identified (see Hardwick *et al.*[88]).

Regulation change

The aim of deregulation in the financial services sector is to improve market efficiency and enhance consumer choice through more competition, but the empirical evidence is mixed. Rees *et al.*[89] find modest efficiency improvements from deregulation for the U.K. and German life insurance markets for the period from 1992 to 1994. Hussels and Ward[24] do not find clear evidence for a link between deregulation and efficiency for the same countries and line of business during the period 1991–2002. Mahlberg[90] even finds decreasing efficiency for Germany considering life and property-liability insurance for the period of 1992–1996, but an increase in productivity. The results for Spain are different: Cummins and Rubio-Misas[91] find clear evidence for total factor productivity growth for the period of 1989–1998, with consolidation reducing the number of firms in the market. Boonyasai *et al.*[92] find evidence for productivity increases in Korea and the Philippines due to deregulation. Considering the U.S., Ryan and Schellhorn[93] find unchanged efficiency levels from the start of the 1990s to the middle of that decade, a period during which risk-based capital (RBC) requirements became effective. Recently, Yuan and Phillips[94] find evidence for cost scope diseconomies and revenue scope economies for the integrated banking and insurance sectors after changes due to the Gramm-Leach-Bliley Act of 1999.

Scale and scope economies

Scale economies have been extensively researched in the context of consolidation and the justification of mergers (see Cummins and Weiss[1]). Although detailed results vary

84 Erhemjamts and Leverty (2007).
85 Greene and Segal (2004).
86 Jeng *et al.* (2007).
87 Xie (2008).
88 Hardwick *et al.* (2004).
89 Rees *et al.* (1999).
90 Mahlberg (2000).
91 Cummins and Rubio-Misas (2006).
92 Boonyasai *et al.* (2002).
93 Ryan and Schellhorn (2000).
94 Yuan and Phillips (2008).

across studies, depending on countries, methods, and time horizons employed, many contributions have found, on average, evidence for increasing returns to scale (see, e.g., Fecher *et al.*[95] for U.K.; Hardwick[96] for Ireland; Hwang and Gao[97] for China; and Qiu and Chen[98] for France). However, the differentiation between size clusters must be considered to achieve more specific results. For example, Yuengert[47] finds increasing returns to scale for U.S. life insurance firms with up to US$15 billion in assets and CRS for bigger firms. In contrast, Cummins and Zi,[11] for the same market, find increasing returns to scale for firms having up to US$1 billion in assets, and decreasing returns to scale for all others except for a few firms with CRS.

The two main hypotheses regarding economies of scope are the conglomeration hypothesis, which holds that operating a diversity of business can add value by exploiting cost and revenue scope economies, and the strategic focus hypothesis, which holds that firms can best add value by focusing on core businesses (see Cummins *et al.*[99]). Considering U.S. life insurers, Meador *et al.*[100] find that diversification across multiple insurance and investment product lines resulted in greater efficiency which is in line with the conglomeration hypothesis. Fuentes *et al.*[101] also find evidence for economies of scope, in their case for Spanish life and non-life insurers. Berger *et al.*[102] show for the U.S. that profit scope economies are more likely to be realised by larger firms. In contrast to all these authors, Cummins *et al.*[99] use cross-frontier analysis and find mixed results with regard to scope economies.

Conclusion and implications for future research

In recent years academics, practitioners and policy-makers have spent significant attention to frontier efficiency techniques in the insurance industry. The purpose of this paper was to provide an overview of this rapidly growing field of research. We analyse 95 studies on efficiency measurement in the insurance sector, provide a systematisation of different applications and highlight recent developments. The paper serves as a comprehensive overview of relevance not only to researchers interested in frontier efficiency studies, but also to regulators and managers for more practical reasons.

DEA is the most frequently applied method in studies conducting frontier efficiency analysis in insurance—55 out of 95 papers apply DEA. In recent years, there have been a number of proposals for improving both econometric and mathematical programming approaches. Proposals include, for example, the development of more appropriate functional forms for the econometric approaches or the introduction of bootstrapping procedures for the mathematical programming approaches. With

[95] Fecher *et al.* (1991).
[96] Hardwick (1997).
[97] Hwang and Gao (2005).
[98] Qiu and Chen (2006).
[99] Cummins *et al.* (2007).
[100] Meador *et al.* (2000).
[101] Fuentes *et al.* (2005).
[102] Berger *et al.* (2000).

regard to the choice of input factors, there seems to be widespread agreement among researchers: 61 out of 95 studies use at least labour and capital as inputs and most of them also add a third category, usually business services. With regard to output measurement, most studies employ the value-added approach (80 out of 95). However, there is some controversy over whether premiums or claims are the better proxy for value added. In recent years, there has been an expansion of frontier efficiency measurement in insurance to new fields of application, such as market structure and risk management. Also, the geographic scope has been rapidly growing, moving from a previously U.S.-focused view to a broad set of countries around the world.

The large number of studies is indicative of increasing interest in the international competitiveness and efficiency of insurance companies and our survey has brought to light a number of opportunities for future research. First of all, significant research potential can be identified at the international level. Most of the existing cross-country comparisons are either focused on Europe—such as Fenn *et al.*[72] and Diacon *et al.*[70] —or consider relatively small datasets—such as Rai,[10] which covers only 106 companies in 11 countries. In this context, the relatively new research topics of market structure (see, e.g., Choi and Weiss[77]) and risk management (see, e.g., Cummins *et al.*[59]) need to be analysed for a larger sample of countries. This would allow us to move away from the U.S. focus of the few studies that have been published to date. Another research idea in this context would be to use cross-frontier analysis to compare the production technology in different countries.

For studies on risk and financial management, a link to the discussion regarding the implementation of new RBC standards for insurers, such as Solvency II (see, e.g., Eling *et al.*[103]), would be of interest. In this case, the possible impact of different solvency proposals on efficiency could be evaluated. Given that corporate governance is often considered as a potential cause of the recent financial market crisis, the link between corporate governance and efficiency needs closer consideration.

A widening of the research arena beyond the U.S. is also needed when it comes to analysis of mergers and efficiency. For example, all studies on this topic except for one (Klumpes[52]) are U.S.-focused. Regarding the coverage of different lines of business, it becomes obvious that most studies have been implemented at relatively high levels of aggregation. Academic contributions on efficiency performance of sublines of business—for example, auto insurance, as done by Choi and Weiss[77] or homeowner insurance—would be of special interest for countries where appropriate data are available.

Most efficiency studies only interpret the efficiency numbers, but the analysis provides a lot more interesting information such as the marginal rate of substitution (if the shadow prices of two inputs are compared), the marginal productivity (if the shadow prices of one input and one output are compared), and the marginal rate of transformation (if the shadow prices of two outputs are compared). The shadow prices, however, have not yet been in focus of much of the literature. Considering stochastic frontier analysis, an important contribution would be to find which

[103] Eling *et al.* (2007).

functional form best fits empirical cost or profit functions, again with possible differences between lines of businesses and countries. Furthermore, efficiency can be measured for each decision-making unit in a company, that is, for each business unit or line of business; the link between capital allocation in insurance companies that is controversially discussed in recent literature (Myers and Read;[104] Gründl and Schmeiser[105]) and efficiency could thus be a fruitful area of future research. Overall, frontier efficiency measurement has been one of the most rapidly growing streams of insurance literature in the last years and so it will be in the future.

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Appendix A

Table A1 Overview of 95 studies on efficiency measurement in the insurance industry

Authors	*Countries*	*No. insurers*	*Sample period*	*Lines of business*	*Method*	*Input type*	*Output type*	*Output approach*	*Main types of efficiencies analyzed*	*Application category*	*Selected findings*
Badunenko *et al*. (2006)	Ukraine	163	2003–2005	Life, non-life	DEA	Fixed assets, current assets, liabilities, equity	Premiums	Value added	Technical, scale	Regulation change	Increased capitalisation requirements have positively influenced Ukrainian insurance market and helped improve both technical and scale efficiency
Barros *et al*. (2005)	Portugal	27	1995–2001	Life, non-life	DEA	Wages, capital, total investment income, premiums issued	Claims paid, profits	Value added	Technical, pure technical, scale	General level of efficiency and evolution over time	Improvement of technical efficiency over time, but deterioration in terms of technological change
Barros and Obijiaku (2007)	Nigeria	10	2001–2005	Life, non-life	DEA	Capital, operative costs, number of employees, total investments	Profits, net premiums, settled claims, outstanding claims, investment income	Value added	Technical, pure technical, scale	General level of efficiency and evolution over time	Most companies are VRS efficient
Berger *et al*. (2000)	U.S.	684	1988–1992	Life, property-liability	TFA, SFA	Labour, business services, reserves, financial equity capital	Invested assets, present value of real losses incurred (P/L), incurred benefits (Life)	Value added	Cost, revenue, profit	Scale and scope economies	Conglomeration hypothesis holds for some types while strategic focus hypothesis dominates for others
Berger *et al*., 1997	U.S.	472	1981–1990	Property-liability	DFA	Labour, business services, debt capital, equity capital	Total real invested assets, present value of losses incurred	Value added	Cost, profit	Distribution systems	Independent agents less cost efficient but equally profit efficient as direct writers
Bernstein (1999)	Canada	12	1979–1989	Life	Cost function	Labour, buildings capital, machinery capital, materials	Number of policies	Physical	n/a	General level of efficiency and evolution over time	Average annual productivity growth of 1% for period 1979–1989

Bikker and van Leuvensteijn (2008)	The Netherlands	84–105	1995–2003	Life	SFA	Acquisition cost, other cost (management cost, salaries, depreciation on capital equipment, etc.)	Premium income, number of outstanding policies, sum total of insured capital, sum total of insured annuities, unit-linked fund policies	Physical	Cost	General level of efficiency and evolution over time	Cost inefficiency of 28% on average
Boonyasai *et al.* (2002)	Korea, Philippines, Taiwan, Thailand	49–110	1978–1997	Life	DEA	Labour, capital, materials	Premium income, net investment income	Value added	Technical, pure technical, scale	Regulation change	Increasing productivity in Korea and Philippines due to deregulation and liberalisation; little effect of liberalisation on productivity in Taiwan and Thailand
Brockett *et al.* (1998)	U.S.	1524	1989	Property-liability	DEA	Surplus previous year, change in capital and surplus, underwriting and investment expense, policy-holder-supplied debt capital	ROI, liquid assets to liability, solvency scores	Financial intermediary	n/a	Distribution systems	Stock companies more efficient than mutuals; agency more efficient marketing system than direct
Brockett *et al.* (2004a)	U.S.	1524	1989	Property-liability	DEA	Surplus previous year, change in capital and surplus, underwriting and investment expense, policy-holder-supplied debt capital	ROI, liquid assets to liability, solvency scores	Financial intermediary	n/a	Financial and risk management, capital utilisation	Solvency scores as output only with limited impact on efficiency scores
Brockett *et al.* (2004b)	U.S.	538	1995	Health	DEA	Premiums (consumer perspective), expenses (societal perspective)	Number of outpatient visits, number of hospital days, total member months	Physical	Technical	Methodology issues, comparing different techniques or assumptions	New game-theoretic DEA model is applied; Independent Practice Organisations (IPAs) are more efficient than the Group/Staff Health Maintenance Organisations (HMOs) from both, the consumer and the societal perspective

Table A1 (*continued*)

Authors	*Countries*	*No. insurers*	*Sample period*	*Lines of business*	*Method*	*Input type*	*Output type*	*Output approach*	*Main types of efficiencies analyzed*	*Application category*	*Selected findings*
Brockett *et al.* (2005)	U.S.	1524	1989	Property-liability	DEA	Surplus previous year, change in capital and surplus, underwriting and investment expense, policy-holder-supplied debt capital	ROI, liquid assets to liability, solvency scores	Financial intermediary	n/a	Organisational form, corporate governance issues	Stock firms with higher inefficiency in the input dimension while mutuals with higher shortfalls in all areas of output; direct systems with more inefficiencies than agency
Carr *et al.* (1999)	U.S.	66	n/a	Life	DEA	Labour (admin., agents), business services, financial capital	Incurred benefits, additions to reserves	Value added	Cost, revenue	Distribution systems	Exclusive dealing insurers less efficient than non-exclusive dealing or direct writers; non-exclusive dealing insurers should focus on fewer product lines; firms adopting one of Porter's 3 generic strategies are more efficient than rivals
Chaffai and Ouertani (2002)	Tunisia	13	1990–2000	Life, non-life	DEA, SFA	Labour, physical capital, financial capital	Total premiums earned	Value added	Technical	General level of efficiency and evolution over time	Significant potential for increase of efficiency
Choi and Weiss (2005)	U.S.	n/a	1992–1998	Property-liability	SFA	Labour (agent, non-agent), materials, equity capital	Present value of losses incurred, total invested assets	Value added	Cost, revenue	Market structure	Cost-efficient firms charge lower prices and earn higher profits; prices and profits higher in revenue-efficient firms
Choi and Weiss (2008)	U.S.	n/a	1992–1998	Property-liability (auto)	SFA	Labour (agent, non-agent), materials, equity capital (assumed same as in Choi and Weiss (2005) according to reference in paper; however, inputs not explicitly described in paper)	Present value of losses incurred, total invested assets (assumed same as in Choi and Weiss (2005), according to reference in paper; however, outputs not explicitly described in paper)	Value added	Cost, revenue	Market structure	Insurers in competitive and non-stringently regulated states may benefit from market power by charging higher unit prices; insurers in these states are on average more cost efficient and cost efficient insurers charge lower prices and earn smaller profits; insurers in some rate regulated states are less revenue and cost-scale efficient than in competitive states.

Cummins (1999)	U.S.	750	1988–1995	Life	DEA	Labour (admin., agents), business services, financial capital	Incurred benefits, additions to reserves	Value added	Pure technical, scale, allocative, cost, revenue	General level of efficiency and evolution over time	Efficiency scores in insurance relatively low compared to other financial services industries; also widely dispersed; small insurers operate with IRS; big insurers with DRS; brokerage system most efficient
Cummins *et al.* (2006)	U.S.	1636	1995–2003	Property-liability	SFA	Labour (admin., agents, risk management), material and business service, debt capital, equity capital	Present value of losses incurred, invested assets, dollar duration of surplus	Value added	Cost	Financial and risk management, capital utilisation	Risk management and financial intermediation increase efficiency
Cummins and Nini, 2002	U.S.	770–970	1993–1998	Property-liability	DEA	Labour (office, sales), materials and business service, financial equity capital	Present value of losses incurred, total invested assets	Value added	Technical, allocative, cost, revenue	Financial and risk management, capital utilisation	On weighted industry average, firms could reduce Labour by 62%, materials by 36%, and capital by 46%; capital is used suboptimally
Cummins and Rubio-Misas, 2006	Spain	331–508	1989–1998	Life, non-life	DEA	Labour, business services, debt capital, equity capital	Non-life losses incurred, life losses incurred, reinsurance reserves, non-reinsurance reserves, invested assets	Value added	Cost, pure technical, allocative, scale	Regulation change	Consolidation leads to growth in TFP and increases number of firms operating with decreasing returns to scale
Cummins *et al.* (2004)	Spain	347	1989–1997	Life, non-life	DEA	Labour, business services, debt capital, equity capital	Life and non-life insurance losses incurred	Value added	Technical, allocative, cost, revenue	Organisational form, corporate governance issues	In cost and revenue efficiency, stocks of all sizes dominate mutuals in the production of stock output vectors, and smaller mutuals dominate stocks in the production of mutual output vectors; larger mutuals are neither dominated by nor dominant over stocks
Cummins *et al.* (1999a)	U.S.	750	1988–1995	Life	DEA	Home-office labour, agent labour, business services (including physical capital), financial capital	Incurred benefits, additions to reserves	Value added	Cost, technical, allocative, pure technical, scale, revenue	Mergers	Mergers and Acquisitions (M&A) beneficial for efficiency; target life insurers achieve greater efficiency gains than firms that have not been involved in M&As

Table A1 (*continued*)

Authors	*Countries*	*No. insurers*	*Sample period*	*Lines of business*	*Method*	*Input type*	*Output type*	*Output approach*	*Main types of efficiencies analyzed*	*Application category*	*Selected findings*
Cummins *et al.* (1996)	Italy	94	1985–1993	Life, non-life	DEA	Labour (acquisition, admin.), fixed capital expense, equity capital	Life insurance: sum of life insurance benefits, changes in reserves, invested assets Non-life insurance: Losses incurred, invested assets	Value added	Technical	General level of efficiency and evolution over time	Stable efficiency over time (70%–78% for the industry) with sharp decline (25% cumulative) in productivity due to technological regress
Cummins and Weiss (1993)	U.S.	261	1980–1988	Property-liability	SFA	Labour, capital, intermediate materials	Discounted incurred losses, loss settlement, intermediary services	Value added	Cost, allocative, technical	General level of efficiency and evolution over time	Large insurers at 90% relative to their cost frontier; medium and small insurers at 80% and 88%, respectively; scale economies with small and medium-sized insurers
Cummins *et al.*, 1999b	U.S.	417	1981–1990	Property-liability	DEA	Labour, materials, debt capital, equity capital	Present value of real losses incurred, total invested assets	Value added	Technical, cost	Organisational form, corporate governance issues	Stock cost frontier dominates mutual cost frontier
Cummins *et al.* (2007)	U.S.	817	1993–1997	Life (incl. health), property-liability	DEA	Labour (office, agent), materials and business service, financial equity capital	Life/health: Real value of incurred benefits, additions to reserves; P/L: Present value of real losses incurred, real invested assets	Value added	Technical, cost, revenue	Scale and scope economies	Weak evidence for existence of economies of scope; although diversified firms dominate specialists in the production of diversified firm output vectors in terms of revenue efficiency for both life-health and property-liability insurance, specialist firms dominate diversified firms for the production of specialist output vectors in revenue efficiency and also dominate diversified firms in cost efficiency for property-liability output vectors

Cummins and Xie (2008)	U.S.	1550	1994–2003	Property-liability	DEA	Labour (admin., agent), materials and business services, financial equity capital	Present value of losses incurred, real invested assets	Value added	Cost, technical, allocative, pure technical, scale, revenue	Mergers	M&As in property-liability insurance are value enhancing; acquiring firms achieved more revenue efficiency gains than non-acquiring firms, and target firms experienced greater cost and allocative efficiency growth than non-targets
Cummins and Zi, 1998	U.S.	445	1988–1992	Life	DEA, DFA, FDH, SFA	Labour, financial capital, materials	Benefit payments, additions to reserves	Value added	Cost, technical, allocative	Methodology issues, comparing different techniques or assumptions	Choice of estimation method can have a significant effect on the conclusions of an efficiency study; efficiency rankings are well preserved among the econometric methods; but the rankings are less consistent between the econometric and mathematical programming methods
Davutyan and Klumpes (2008)	7 European countries	472	1996–2002	Life, non-life	DEA	Labour, business services, equity capital	Present value of losses incurred, premiums, invested assets	Value added	Technical, pure technical, scale	Mergers	In life insurance, after mergers, business inputs replace labour for both targets and acquirers, but these effects do not apply to non-life targets; mergers do not significantly impact acquirer behavior
Delhausse *et al.* (1995)	Belgium, France	434	1984–1988	Non-life	DEA, SFA	Labour costs, other outlays (capital consumption, purchase of equipment and supplies, etc.)	Premiums	Value added	Technical, scale	Intercountry comparisons	French companies on average more efficient than Belgian ones; overall low efficiency levels; high correlation between results of both approaches
Diacon (2001)	6 European countries	431	1999	General insurance	DEA	Total operating expenses, total capital, total technical reserves, total borrowings from creditors	Net earned premiums, total investment income	Value added	Technical	Intercountry comparisons	Average efficiencies: U.K. (77%), France (67%), Germany (70%), Italy (56%), the Netherlands (69%), Switzerland (66%)
Diacon *et al.* (2002)	15 European countries	454	1996–1999	Life incl. pension, and health	DEA	Total operating expenses, total capital, total technical reserves, total borrowings from creditors	Net earned premiums, total investment income	Value added	Pure technical, scale, mix	Intercountry comparisons	Striking international differences and decreasing levels of average technical efficiency over sample period

Table A1 (*continued*)

Authors	*Countries*	*No. insurers*	*Sample period*	*Lines of business*	*Method*	*Input type*	*Output type*	*Output approach*	*Main types of efficiencies analyzed*	*Application category*	*Selected findings*
Diboky and Ubl (2007)	Germany	90	2002–2005	Life	DEA	Labour, business services, financial debt capital, equity capital	Gross premium, net income	Value added	Technical, cost and allocative efficiency	Organisational form, corporate governance issues	Stock ownership is superior to mutual and public structure
Donni and Fecher (1997)	15 OECD countries	n/a	1983–1991	Life, non-life	DEA	Labour	Net premiums	Value added	Technical	Intercountry comparisons	Average efficiency levels rather high and dispersed; growth in productivity observed in all countries and due to improvements in technical progress
Donni and Hamende (1993)	Belgium	300	1982–1988	Life, non-life	FDH	Labour cost, other cost	Premiums; alternatively, losses incurred	Value added	Technical	Organisational form, corporate governance issues	Superior efficiency of non-profit insurance companies
Eling and Luhnen (2008)	36 countries	6462	2002–2006	Life, non-life	DEA, SFA	Labour and business service, financial debt capital, equity capital	Non-life: claims + additions to reserves; Life: benefits + additions to reserves; Investments	Value added	Technical, cost	Intercountry comparisons	Technical and cost efficiency growth in international insurance markets from 2002 to 2006, with large differences across countries; Denmark and Japan have the highest average efficiency, the Philippines is the least efficient
Ennsfellner *et al.* (2004)	Austria	97–105	1994–1999	Life/ health, non-life	SFA	Net operating expenses, equity capital, technical provisions	Health/life: Incurred benefits, changes in reserves, total invested assets Non-life: Losses incurred, total invested assets	Value added	Technical	Regulation change	Deregulation had positive effects on production efficiency

Erhemjamts and Leverty (2007)	U.S.	1070	1995–2004	Life	DEA	Labour, business services, equity capital, policyholder-supplied debt capital	Incurred benefits, additions to reserves	Value added	Technical	Organisational form, corporate governance issues	Stock production technology dominates mutual technology; mutuals that are further away from mutual efficient frontier more likely to demutualisation; access to capital important reason for demutualisation
Fecher *et al.* (1993)	France	327	1984–1989	Life, non-life	DEA, SFA	Labour cost, other outlays	Gross premiums	Value added	Technical	General level of efficiency and evolution over time	High correlation between parametric and non-parametric results; wide dispersion in the rates of inefficiency across companies
Fecher *et al.* (1991)	France	327	1984–1989	Life, non-life	SFA	Labour cost, other outlays	Gross premiums	Value added	Cost	Scale and scope economies	Increasing returns to scale
Fenn *et al.* (2008)	14 European countries	n/a	1995–2001	Life, non-life, composite	SFA	Capital, technical provisions, labour, debt capital	Net incurred claims (= gross claims paid − claims received from reinsurers + increase in loss reserves + bonuses and rebates)	Value added	Cost	Market structure	Most European insurers operating under IRS; size and domestic market share lead to higher levels of cost inefficiency
Fuentes *et al.* (2001)	Spain	55–70	1987–1994	Health, life, non-life	SFA	Labour costs, composite input	Annual premiums	Value added	Technical	Methodology issues, comparing different techniques or assumptions	Malmquist index of productivity growth can also be estimated on basis of parametric frontier approach
Fuentes *et al.* (2005)	Spain	n/a	1987–1997	Health, life, property-liability	SFA	Labour costs, composite input	Annual premiums	Value added	Technical	Scale and scope economies	Overall low productivity growth over time (less than 2% per year), multi-branch companies perform better than specialised firms
Fukuyama (1997)	Japan	25	1988–1993	Life	DEA	Labour (office, sales), capital	Insurance reserves, loans	Financial intermediary	Technical, pure technical, allocative, scale	Organisational form, corporate governance issues	Mutual and stock companies possess identical technologies; productive efficiency and productivity performances differ across 2 ownership types and different economic conditions

Table A1 (*continued*)

Authors	*Countries*	*No. insurers*	*Sample period*	*Lines of business*	*Method*	*Input type*	*Output type*	*Output approach*	*Main types of efficiencies analyzed*	*Application category*	*Selected findings*
Fukuyama and Weber (2001)	Japan	17	1983–1994	Non-life	DEA	Labour (office, sales), capital	Reserves, loans, investments	Financial intermediary	Technical	Methodology issues, comparing different techniques or assumptions	Productivity and technological progress over time in Japan
Gardner and Grace (1993)	U.S.	561	1985–1990	Life	DFA	Labour, physical capital, misc. items	Premiums, securities investments	Value added	Cost	General level of efficiency and evolution over time	Persistent inefficiency
Grace and Timme (1992)	U.S.	423	1987	Life	Cost function	Labour, capital, misc. expenses	Premiums, annuities, investments	Value added	n/a	Scale and scope economies	Most firms have significant economies of scale; largest agency companies with approximately constant returns to scale; lack of cost complementaries in the multiproduct insurance firms
Greene and Segal (2004)	U.S.	136	1995–1998	Life	SFA	Labour, capital, materials	Premiums, investments	Value added	Cost	Organisational form, corporate governance issues	Inefficiency negatively associated with profitability; stock companies as efficient and profitable as mutual companies
Hao (2007)	Taiwan	26	1981–2003	Life	DFA	Labour, physical capital, claims	Premiums, investments	Value added	Cost	General level of efficiency and evolution over time	Firms with large market share tend to be cost efficient
Hao and Chou (2005)	Taiwan	26	1977–1999	Life	DFA, SFA	Labour, physical capital, claims	Premiums, investments	Value added	Cost	General level of efficiency and evolution over time	Firms with larger market share are more profitable; product diversification does not improve efficiency

Hardwick (1997)	U.K.	54	1989–1993	Life incl. pension, and health	SFA	Labour, capital	Premiums	Value added	Economic, scale, total inefficiency	General level of efficiency and evolution over time	High level of inefficiency; increasing returns to scale
Hardwick *et al.* (2004)	U.K.	50	1994–2001	Life	DEA	Labour, capital	Incurred benefits, additions to reserves	Value added	Cost, technical, allocative	Organizational form, corporate governance issues	Cost efficiency positively related to size of corporate board of directors
Hirao and Inoue (2004)	Japan	33	1980–1995	Property-liability	SFA	Labour, agencies, materials	Real incurred losses (net claims paid and changes in loss reserves)	Value added	Cost	Scale and scope economies	Statistically significant economies of scale and scope
Huang (2007)	China	n/a	1999–2004	Life, property-liability	SFA	Labour, capital, business services	Premiums earned, incurred benefits and additions to reserves, total invested assets	Value added	Cost, profit	General level of efficiency and evolution over time	Non-state-owned companies and foreign companies are superior in terms of cost efficiency to the property insurance industry, state-owned companies, and domestic companies
Hussels and Ward (2006)	Germany and U.K.	47 (U.K.) 31 (GE)	1991–2002	Life	DEA, DFA	Labour, capital	Net written premiums, additions to reserves	Value added	Cost, technical, allocative, scale	Regulation change	Comparability of results from DEA and DFA; U.K. efficiency frontier less efficient than German frontier; no clear evidence for link between deregulation and efficiency levels
Hwang and Gao (2005)	Ireland	11	1991–2000	Life	DFA	Labour (admin., agent), financial capital	Insurance benefits, investable funds	Value added	Cost	Scale and scope economies	Increasing returns to scale; magnitude of cost economies varies with firm size
Hwang and Kao (2008a)	Taiwan	17	1999–2002	Non-life	DEA	Business and administrative expenses, commissions and acquisition expenses	First stage: Direct written premiums, reinsurance premiums Second stage: underwriting income, investment income	Two-stage production process	n/a	Methodology issues, comparing different techniques or assumptions	Two-stage DEA reveals significance of operating performance effectively; each company can realise its strengths and weaknesses in different production stages

Table A1 (*continued*)

Authors	*Countries*	*No. insurers*	*Sample period*	*Lines of business*	*Method*	*Input type*	*Output type*	*Output approach*	*Main types of efficiencies analyzed*	*Application category*	*Selected findings*
Hwang and Kao (2008b)	Taiwan	24	2001–2002	Non-life	DEA	Operation expenses, insurance expenses	First stage: direct written premiums, reinsurance premiums; Second stage: underwriting income, investment income	Two-stage production process	n/a	Methodology issues, comparing different techniques or assumptions	New relational model is more reliable in measuring efficiencies than independent models
Jeng and Lai (2005)	Japan	19	1985–1994	Non-life	DEA	VA: Labour, business services, capital (debt + equity) FI: Surplus previous year/assets, change in surplus/assets, underwriting + investment expenses/assets, policy-holder debt capital/assets	VA: Number of policies, total invested assets FI: Return on Assets (ROA), three principal components of financial conditions	Value added/financial intermediation	Technical, cost	Organisational form, corporate governance issues	Keiretsu firms more cost efficient than nonspecialised independent firms (NSIFs); otherwise not possible to reject null hypothesis that all equally efficient; deteriorating efficiency for all company types; FI and VA approaches with different, but complementary, results
Jeng *et al.* (2007)	U.S.	11	1980–1995	Life	DEA	VA: Labour, business services, capital (debt + equity) FI: Surplus previous year/assets, change in surplus/assets, underwriting + investment expenses/assets, policy-holder debt capital/assets	VA: Number of policies, total invested assets FI: Return on Assets (ROA), three principal components of financial conditions	Value added/financial intermediation	Cost, technical, allocative	Organisational form, corporate governance issues	For both approaches, no efficiency improvement after demutualisation; exception: improvement for mutual control insurers under FI approach
Kessner (2001a)	Germany and U.K.	87 (U.K.) 78 (Germany)	1994–1999	Life	DEA	New business cost, administration cost, cost for capital management, reinsurance contributions	Gross and net written premiums, interest on capital	Value added	Technical	Intercountry comparisons	British insurers more efficient than German insurers; increasing efficiency in both markets

Kessner (2001b)	Germany	75	1989–1994	Life	DEA	New business cost, administration cost, cost for capital management, reinsurance contributions	Sum insured (new and existing business), net returns on capital investments	Value added	Technical, scale	Scale and scope economies	Small companies with increasing returns to scale; big companies with decreasing returns to scale
Kessner and Polborn (1999)	Germany	110	1990–1993	Life	DEA	New business cost, administration cost	Sum insured of new and in-force business	Value added	Technical	General level of efficiency and evolution over time	High level of inefficiency
Kim and Grace (1995)	U.S.	248	1988–1992	Life	DFA	Labour (agent, non-agent), capital, materials	Claims, changes in reserves, investment expenses	Value added	Cost	Mergers	Smaller firms with larger cost savings from mergers than large firms; no cost savings in mergers of mutuals; mergers of efficient with less efficient companies increase combined firm efficiency
Klumpes (2004)	U.K.	40	1994–1999	Life	SFA	Labour, materials, policy supplied debt capital, financial equity capital	Claims, real invested assets	Value added	Cost, profit	Distribution systems	IFA-based firms less cost and profit efficient than AR/CR firms
Klumpes (2007)	7 European countries	1183	1997–2001	Life, general insurance	DEA	Labour, business services, debt capital, equity capital	Premiums, investment income	Value added	Cost, technical, allocative, pure technical, scale, revenue	Mergers	Acquiring firms achieve greater efficiency gains than either target firms or firms not involved in mergers; no beneficial effect of mergers on target firms; M&A driven mostly by solvency objectives
Leverty and Grace (2008)	U.S.	n/a	1989–2000	Property-liability	DEA	VA: Labour (admin, agent), materials and business services, financial equity capital, policy-holder-supplied debt capital FI: Policy-holder surplus, underwriting and investment expenses, policy-holder-supplied debt capital	VA: Real losses incurred, real invested assets FI: ROI, liquid assets to liabilities, solvency score	Value added, financial intermediation	Pure technical, scale, technical, allocative, cost, revenue	Methodology issues, comparing different techniques or assumptions	Value-added and financial intermediation approach are not consistent; value-added approach closely related to traditional measures of firm performance; financial intermediation approach generally not

Table A1 (*continued*)

Authors	*Countries*	*No. insurers*	*Sample period*	*Lines of business*	*Method*	*Input type*	*Output type*	*Output approach*	*Main types of efficiencies analyzed*	*Application category*	*Selected findings*
Leverty *et al.* (2004)	China	20–41	1995–2002	Life, property-casualty	DEA	Business expenses, financial equity capital, debt capital	Life: Net premiums written, real invested assets P&C: Losses incurred, real invested assets	Value added	Technical, scale, pure technical	General level of efficiency and evolution over time	Productivity growth; in P&C due to presence of technically efficient foreign firms
Luhnen (2008)	Germany	295	1995–2006	Property-liability	DEA	Labour and business service, financial debt capital, equity capital	claims incurred; total invested assets	Value added	technical, cost, allocative, scale	General level of efficiency and evolution over time	Potential for the market to improve by about 20% in terms of technical efficiency and about 50% in terms of cost efficiency moderate total factor productivity growth; low efficiency growth
Mahlberg (1999)	Austria and Germany	36 (Austria) 118 (Germany)	1992–1996	Life, health, property-liability	DEA	Administration and distribution cost (1 input)	Claims, change in reserves, refund of premium	Value added	Technical	Intercountry comparisons	Inefficiencies in both markets; Austrian insurers more efficient than German insurers
Mahlberg (2000)	Germany	348	1992–1996	Life, health, property-liability	DEA	Administration and distribution cost (1 input)	Claims, change in reserves, refund of premium	Value added	Technical	Regulation change	Decreasing efficiency; increasing productivity
Mahlberg and Url (2000)	Germany	464–533	1992–1996	Life, health, property-liability	DEA	Administration and distribution cost (1 input)	Claims, net change in provisions, allocated investment returns, bonuses and returned premiums	Value added	Technical	Regulation change	Still cost-saving potential; increasing divergence between fully efficient firms and efficiency laggards; low cost-savings potential from further mergers
Mahlberg and Url (2003)	Austria	59–70	1992–1999	Life, health, property-liability	DEA	Administration and distribution cost (1 input), cost of capital investments	Claims, net change in provisions, allocated investment returns, bonuses and returned premiums	Value added	Technical	Regulation change	Still considerable inefficiency; increased productivity

Mansor and Radam (2000)	Malaysia	12	1987–1997	Life	DEA	Claims, commission, salaries, expenses, other cost	New policy issued, premium, policy in force	Value added	Technical	General level of efficiency and evolution over time	Productivity growth; but low compared to real growth of economy
Meador *et al.* (2000)	U.S.	358	1990–1995	Life	DFA	Labour, physical capital, misc. items	Premiums, securities investments	Value added	Cost	Scale and scope economies	Multi-product firms more efficient than focused firms
Noulas *et al.* (2001)	Greece	16	1991–1996	Non-life	DEA	Salaries and expenses (1 input) and payment to insurers and expenses incurred in the production of services (1 input)	Premium income, revenue from investment activities	Value added	Technical	General level of efficiency and evolution over time	Industry highly inefficient, with notable differences between different companies
Qiu and Chen (2006)	China	14–32	2000–2003	Life	DEA	Labour, equity capital, other	Benefit payments, additions to reserve, yield of investment	Value added	Technical, pure technical, scale	General level of efficiency and evolution over time	Average technical efficiency declining over time; increasing returns to scale
Rai (1996)	11 OECD countries	106	1988–1992	Life incl. health, non-life	DFA, SFA	Labour, capital, benefits and claims	Premiums (life and non-life)	Value added	Cost	Intercountry comparisons	Firms in Finland and France with lowest inefficiency; firms in U.K. with highest; small firms more cost efficient than large firms; specialised firms more cost efficient than combined firms
Rees *et al.* (1999)	Germany and U.K.	n/a	1992–1994	Life	DEA	Distribution cost, administration cost	Total premium income and change in total premium income (U.K.), aggregate sum insured and change in aggregate sum insured (Germany)	Value added	Technical	Regulation change	Looser regulation and increased competition increase efficiency
Ryan and Schellhorn (2000)	U.S.	321	1990–1995	Life	DFA	Labour, financial capital, materials	Benefit payments, additions to reserves	Value added	Cost	Regulation change	Unchanged efficiency levels after RBC became effective
Toivanen (1997)	Finland	21	1989–1991	Non-life	SFA	Labour	Number of units produced	Physical	Cost	Scale and scope economies	Diseconomies of scale at firm and economies of scale at branch level; economies of scope in production

Table A1 (*continued*)

Authors	*Countries*	*No. insurers*	*Sample period*	*Lines of business*	*Method*	*Input type*	*Output type*	*Output approach*	*Main types of efficiencies analyzed*	*Application category*	*Selected findings*
Tone and Sahoo (2005)	India	n/a	1982–2001	Life	DEA	Labour, business services, debt capital, equity capital	Present value of real losses incurred, ratio of liquid assets to liabilities	Value added	Technical, allocative, cost, scale	General level of efficiency and evolution over time	Increasing allocative inefficiencies after 1994; increase in cost efficiency in 2000
Trigo Gamarra (2008)	Germany		1995–2002	Life	SFA	Acquisition and administration expenses, equity capital	Incurred benefits, additions to reserves, bonuses and rebates	Value added	Cost, profit	Regulation change	Positive total factor productivity growth, mainly driven by positive technological change; technical cost and profit efficiency stable on average, but significant positive scale efficiency change; market consolidation leads to efficiency gains for insurers
Trigo Gamarra and Growitsch (2008)	Germany	115	1997–2005	Life	DEA	Acquisition and administration expenses, equity capital	Incurred benefits, additions to reserves, bonuses and rebates	Value added	Cost, profit, scale	Distribution systems	Specialised single-channel insurers do not outperform multi-channel insurers in terms of cost or profit efficiency
Turchetti and Daraio (2004)	Italy	45	1982–2000	Motor	DEA	Acquisition production and organisation cost, overhead and administrative expenses, fixed capital, financial equity capital, policy-holder debt capital	Incurred losses, invested assets	Value added	Technical, cost, allocative, scale	Regulation change	Cost efficiency and total factor productivity increase, especially in the second half of the 1990s
Vencappa *et al.* (2008)	14 European countries	n/a	1995–2001	Life, non-life	SFA	Labour and materials, financial capital, debt capital	Incurred claims	Value added	Technical	General level of efficiency and evolution over time	Temporal variations in rate of overall productivity growth for life and non-life, driven by patterns of technological progress and regress, together with consistent positive contributions from scale efficiency; in most years, modest growth in technical efficiency

Ward (2002)	U.K.	44	1990–1997	Life	SFA	Labour, capital	Claims, additions to reserves	Value added	Cost, revenue, profit	Distribution systems	Cost benefits for firms focusing on one mode of distribution
Weiss (1986)	U.S.	2	1976–1980	Life	Index	Labour (supervisor, agent, other); materials; capital (home office, field)	Number of policies, constant dollar insurance in force, real premium	n/a	n/a	Methodology issues, comparing different techniques or assumptions	Theoretically sound method for measuring productivity in life insurance industry has been introduced
Weiss (1991a)	U.S.	100	1980–1984	Property-liability	SFA	Labour (agent, supervisory, non-supervisory), material, capital	Incurred losses, reserves	Value added	Technical, allocative, scale	General level of efficiency and evolution over time	Estimated inefficiency costs of 12–33% of premiums
Weiss (1991b)	France, Germany, Japan, Switzerland, U.S.	n/a	1975–1987	Property-liability	Index	Labour, capital	Incurred losses, reserves	Value added	n/a	Intercountry comparisons	Japan with weakest productivity growth; U.S. and Germany with overall high productivity
Wende *et al.* (2008)	Germany	40	1988–2005	Property-liability	DEA	Operating expenses, equity capital, debt capital	Claims incurred, total invested assets	Value added	Technical, allocative, cost	Organisational form, corporate governance issues	Regulation influences comparative advantages of different organisational forms in terms of efficiency
Worthington and Hurley (2002)	Australia	46	1998	General insurance	DEA	Labour, information technology, physical capital, financial capital	Net premium revenues, invested assets	Value added	Pure technical, scale, allocative, cost	General level of efficiency and evolution over time	Low average level of efficiency; mostly due to allocative inefficiency
Wu *et al.* (2007)	Canada	71–78	1996–1998	Life incl. health	DEA	Prod: Labour expenses, operating exp., capital equity, claims incurred Inv: Net actuarial reserves, investment exp., total investments, total segregated funds	Prod: Net premiums written, net income Inv: Investment gains in bonds and mortgages, investment gains in equities and real est.	Value added/ financial intermediation	Systematic, production, investment	Methodology issues, comparing different techniques or assumptions	New model allows integration of production performance and investment performance; Canadian companies operated very efficiently

Table A1 (*continued*)

Authors	*Countries*	*No. insurers*	*Sample period*	*Lines of business*	*Method*	*Input type*	*Output type*	*Output approach*	*Main types of efficiencies analyzed*	*Application category*	*Selected findings*
Wu *et al.* (2007)	Canada	71–78	1996–1998	Life incl. health	DEA	Prod: Labour expenses, general operating expenses, capital equity, claims incurred Inv: Net actuarial reserves, investment expenses, total investments, total segregated funds	Prod: Net premiums written, net income Inv: Investment gains in bonds and mortgages, investment gains in equities and real estate	Value added/ financial intermediation	Systematic, production, investment	Methodology issues, comparing different techniques or assumptions	New model allows integration of production performance and investment performance; Canadian companies operated very efficiently
Xie (2008)	U.S.	107	1993–2004	Property-liability	DEA	Labour, (admin, agent), business service and materials, financial equity capital	Present value of losses incurred, real invested assets	Value added	Cost, revenue	Organisational form, corporate governance issues	IPO firms perform no worse than private firms in terms of cost and revenue efficiency changes
Yang (2006)	Canada	72	1998	Life incl. health	DEA	Prod: Labour expenses, general operating expenses, capital equity, claims incurred Inv: Net actuarial reserves, investment expenses, total investments, total segregated funds	Prod: Net premiums written, net income Inv: Investment gains in bonds and mortgages, investment gains in equities and real estate	Value added/ financial intermediation	Systematic, technical (production), investment	Methodology issues, comparing different techniques or assumptions	New model allows integration of production performance and investment performance; Canadian companies operated fairly efficiently
Yao *et al.* (2007)	China	22	1999–2004	Life, non-life	DEA	Labour, capital, payment and benefits	Premiums, investment income	Value added	Technical	General level of efficiency and evolution over time	Average efficiency of 0.77 for non-life and 0.70 for life companies

Yuan and Phillips (2008)	U.S.	613	2003–2005	life, property-liability, (commercial banks, thrifts)	SFA	Labour (admin, agent), material and physical capital, financial equity capital, debt capital	P/L: Present value of real losses incurred Life: Incurred benefits plus additions to reserves	Value added	Cost, revenue, profit scope	Regulatory change	Significant number of cost scope diseconomies, revenue scope economies, weak profit scope economies exist in post-GLB integrated banking and insurance sectors
Yuengert (1993)	U.S.	765	1989	Life incl. accident and health	SFA, TFA	Labour, physical capital	Reserves, additions to reserves	Value added	Cost, scale	Scale and scope economies	Economies of scale, but not for whole sample; x-inefficiency 35–50%; weakness of TFA; half-normal SFA specification not flexible enough
Zanghieri (2008)	14 European countries	n/a	1997–2006	Life, non-life	SFA	Labour, debt capital, equity capital	Claims paid, additions to reserves	Value added	Cost, profit	Intercountry comparisons	Country-specific factors do not seem to influence the efficiency of life insurers, but do have a strong effect on the efficiency of non-life insurers

Abbreviations: DEA: Data envelopment analysis; DFA: Distribution-free approach; FDH: Free disposal hull; SFA: Stochastic frontier approach; TFA: Thick frontier approach. Four contributions to performance measurement in insurance by Weiss (1986, 1991b), Grace and Timme (1992) and Bernstein (1999) are excluded from the overview, but included in this table, as they are not efficient-frontier based.

Appendix B

Search strategy

Our search strategy consists of four steps. Table B1 summarises these four steps and their most important elements (called sub-steps in Table B1).

Table B1 Search Strategy

Number	*Step*	*Sub-steps*
1	Definition of the search strategy	1.1. Define a list of relevant key words (based on the Cummins and Weiss (2000); Berger/Humphrey (1997) surveys and other more recent articles): Insurance, Efficiency, Productivity, Malmquist Index, Data Envelopment Analysis, Stochastic Frontier Analysis, … 1.2. Define a list of relevant authors: David Cummins, Mary Weiss, Allen N. Berger, Maria Rubio-Misas, Sharon Tennyson, Martin F. Grace, … 1.3. Define a list of relevant journals: *The Geneva Papers on Risk and Insurance*, *The Geneva Risk and Insurance Review*, *Journal of Risk and Insurance*, *Risk Management and Insurance Review*, *Journal of Productivity Analysis*, *European Journal of Operational Research*, *Journal of Banking and Finance* …
2	Implementation of the search strategy (data collection)	2.1. Search for articles in the relevant journals using the key words 2.2. Search for articles and working papers via Google Scholar using the key words (for example, "Data Envelopment Analysis" and Insurance, "Stochastic Frontier Analysis" and Insurance) 2.3. Search for articles via publication databases such as Social Science Research Network (http://www.ssrn.com/), EBSCO (http://ejournals.ebsco.com/), and Science Direct (http://www.sciencedirect.com/) using the key words 2.4. Search for articles and working papers on the web pages of the relevant authors (David Cummins, Mary Weiss, … ; especially in their list of publications) 2.5. Follow cross-references from overview sections of found papers 2.6. Attend and systematically scan conferences on frontier efficiency (e.g., JBF conference on "the Uses of Frontier Efficiency Methodologies for Performance Measurement in the Financial Services Sector") and insurance (e.g., ARIA annual meeting, EGRIE conference) to identify most recent working papers on the topic
3	Evaluation of search results	3.1. Data preparation according to the categories published in the list in the Appendix A of the paper (authors, countries, number of insurers, sample period, lines of business covered, used methods, inputs and outputs used, types of efficiency analyzed, application category, selected findings) 3.2. Delete articles that are not efficient frontier based, but focus mostly on productivity or other aspects 3.3. Delete working papers that do not have sufficient quality
4	Revision and completion of search based on comments of colleagues/ on conferences	4.1. We have sent the manuscript including the list of papers to colleagues and asked them if there is something missing; additionally, presented search results at conferences and collected feedback 4.2. The feedback of the colleagues was integrated

Table B2 Matrix-like review strategy for journals

Keywords	*Efficiency*	*Productivity*	*Data envelopment analysis*	*Stochastic frontier analysis*	…
Journals					
Geneva papers on Risk and Insurance					
Geneva Risk and Insurance Review					
Insurance: Mathematics and Economics					
Journal of Risk and Insurance					
Risk Management and Insurance Review …					

The first step was to define a search strategy based on a list of keywords, journals, and authors. In the second step we implemented the search strategy, that is, we systematically scanned the relevant literature for articles and working papers. For the journals this resulted in a matrix-like review strategy as presented in Table B2. Important here was, however, not to restrict on existing authors and journals in the field, but to have a broader focus including a Google Scholar search and a search in the publication databases such as EBSCO and Science Direct. An element of step 2 also was to attend relevant academic conferences, both on frontier efficiency and on risk management and insurance. The third step then was to systematically analyse the found articles on a set of predefined criteria. This step resulted in the large table presented in Appendix A of this paper. Here we have deleted articles that are not efficient frontier based, but focus on productivity or other aspects. We have also deleted articles that were not of convincing quality (for example, we found many working papers with inaccurate and incorrect presentation in terms of methodology and language and decided not to integrate these in our review; all these articles are, of course, available upon request). Finally, we sent the paper to colleagues in order to receive some feedback, especially in terms of completeness. After integrating the comments from colleagues, we ended up with a list of 95 working papers (Table A).