Frontier efficiency methodologies to measure performance in the insurance industry: Overview, systematization, and recent developments

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Frontier efficiency methodologies to measure performance in the insurance industry: Overview, systematization, and recent developments

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Abstract

The purpose of this article 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 categorize 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, e.g., with regard to analysis of organizational forms, market structure and risk management, especially in the international context.

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1. 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 minimization and revenue maximization. They can be used to direct management efforts to the areas that need improvement, to identify attractive targets for mergers and acquisitions, and for many other purposes. Performance measurement also can 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 summarize performance in a single statistic that controls for differences among firms using a sophisticated multidimensional framework (see Cummins/Weiss, 2000).

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/Humphrey (1997) and Cummins/Weiss (2000) surveyed eight and 21 studies, respectively. Now, less than ten 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 US-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 categorize the 95 studies into 10 different areas of application and discuss selected results.

Our four main results can be summarized 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, e.g., 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 US 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, e.g., especially in the field of organizational form, market structure, risk management, and with regard to different lines of business. As most studies focus on US 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 systematization 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 well as for regulators and managers interested in the results and implications of frontier efficiency studies.

The remainder of the paper is organized as follows. Section 2 starts with an overview of the 95 studies focusing on frontier efficiency in the insurance industry, subdivided in ten application areas. Section 3 introduces the two principal methodological approaches to efficiency measurement, surveys their implementation in insurance studies, and highlights recent innovations. Section 4 contains an overview on the usage of input and output factors. In Section 5 we get back to ten application areas and discuss the most important findings from the 95 studies. Finally, Section 6 concludes and highlights options for future research.

2. 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/Humphrey (1997), which focuses on banks. The second one by Cummins/Weiss (2000) focuses on the insurance industry and covers 21 studies that have been published until the year 1999. Three studies (Weiss, 1986, Weiss, 1991b, Bernstein, 1999) that are considered in Cummins/Weiss (2000) 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 ten different application areas (first column). Some of these application areas have been selected following Berger/Humphrey's (1997) overview for the banking sector. However, we extended and refined their systematization 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 analyzed, sample periods, lines of business covered, and main findings, is available upon request.[1]

Insert Table 1 here

[1] In order to identify and summarize articles, we have specified a search strategy based on a list of relevant key words, journals, databases, and authors. All details on the search strategy are available upon request.

3. 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 standardized 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 the company's improvement potential in terms of efficiency (see, e.g., Cooper et al., 2007). Different types of efficient frontiers can be estimated. In the simplest case, a production frontier is estimated, assuming that companies minimize inputs conditional on given output levels (input-orientation) or maximize 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.[2]

3.1. 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 generalized translog, Fourier flexible, or composite cost— they differ in their distributional assumptions of the inefficiency and random components (see Cummins/Weiss, 2000). The *stochastic frontier approach* (SFA) 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.

[2] 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.

Finally, the *thick frontier approach* (TFA) 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/Lovell, 2000).

The most commonly used econometric approach is *stochastic frontier analysis* (SFA), which was first proposed by Aigner et al. (1979). 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/Weiss, 2000). 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., Choi and Weiss, 2005; Cummins and Weiss, 2000; Cummins and Zi, 1998; Rai, 1996):

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

where C_i are total observed costs of insurer i. $\ln \hat{C}(p_i, y_i)$, 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, modeled 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 (modeled by the term v_i) is inefficiency, which is usually assumed to be half-normally distributed. To estimate efficiency, $\ln \hat{C}(p_i, y_i)$ 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:

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

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 Equation (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 normalized quadratic (see Morrison/Berndt, 1982), and generalized translog (see Caves et al., 1980). The composite cost (see Pulley/Braunstein, 1992) or the Fourier flexible form (see Gallant, 1982) 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/Humphrey, 1997).

3.2. 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 *data envelopment analysis* (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 optimization result. DEA models can be specified under the assumption of constant (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., Cooper et al., 2007; Cummins and Nini, 2002; Worthington and Hurley, 2002). Efficiency *e* of an insurer *i* is measured by the ratio:

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

where y_i is a vector with outputs , j $y_{j,i}$ = 1,…, z, of firm *i*. x_i is a vector with inputs $x_{k,i}$, k = 1,…, 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 optimization problem must be solved in order to obtain optimal input and output weights for the maximization of efficiency:

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

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

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

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/Seiford/Tone, 2007). 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/Weiss, 2000, 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, i.e., 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., 1999b; Cummins/ Rubio-Misas, 2006). 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, 1993; Cummins/Weiss, 2000). Overall, the total factor productivity growth is relatively lower in the insurance industry, especially compared to manufacturing industries (Bernstein, 1999; Fuentes et al., 2001; Luhnen, 2008).

3.3. Comparison and discussion of recent developments

Both the econometric and mathematical programming have their advantages and disadvantages and there is no consensus as to which method is superior (see, e.g., Cummins/Zi, 1998; Hussels/Ward, 2006). 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/Humphrey, 1997).

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/Zi (1998) and consider multiple approaches, ideally from both the econometric and mathematical programming sides. Most of these find highly correlated re-

sults when ranking firms by their relative efficiency according to different approaches (see, e.g., Hussels/Ward, 2006). However, both approaches illuminate efficiency from different perspectives and thus deliver different insights. This is why we follow Cummins/Zi (1998) 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/Weiss, 2000).

In recent years, there have been a number of proposals for the improvement of efficient 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. 2008). Also, Bayesian stochastic frontier models (see van den Broek et al., 1994), featuring advantages such as exact small-sample inference on efficiencies, have been applied (see, e.g., Ennsfellner/Lewis/ Anderson, 2004). 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 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., Greene/Segal, 2004; Huang/Liu, 1994). Fenn et al. (2008) address the drawback of the conditional mean approach, that the variance of the random and efficiency errors is as-

sumed constant. Following a procedure by Kumbhakar/Lovell (2000), 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 nonparametric DEA for insurance companies, Fuentes/Grifell-Tatjé/Perelman (2001) 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 (1993) 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/Humphrey, 1997). Also, DEA efficiency estimates have been shown to be biased upward in finite examples (see, e.g., Simar/Wilson, 1998). In this context, the bootstrapping procedure proposed by Simar/Wilson (1998) 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/Weiss/Zi, 2007; Erhemjamts/Leverty, 2007; Diboky/Ubl, 2007). Simar/Wilson (2007) 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 organizational forms, comparing technical, cost, and revenue efficiency of stocks and mutual insurers (see Cummins et al., 1999b, 2003; Cummins et al., 2004). It has

also been used for the analysis of scope economies, comparing diversified and specialist firms (see Cummins et al., 2003). Finally, Brocket et al. (2004, 2005) 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.

4. Input and output factors used in efficiency measurement

4.1. Choice of input factors

There are three main insurance inputs: *labour*, *business service and materials*, and *capital*. Labour can be further divided into agent and home-office labour. The category of business service 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/Tennyson/Weiss, 1999; Cummins/Weiss, 2000). 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 US Department of Labour data on average weekly wages for SIC Class 6311 (home-office life insurance labour), can be used in the case of studying the US insurance industry (see, e.g., Berger/Cummins/Weiss, 1997; Cummins/Zi, 1998). 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/Weiss/Zi, 1999).

61 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—e.g., total operating expenses—without decomposing them into quantities and prices (see, e.g., Rees et al., 1999; Mahlberg/Url, 2003). Nine studies do not cover capital explicitly,

i.e., 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., 1998). The choice of input prices is mainly determined by the data that are publicly available in the countries under investigation.

4.2. 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 policyholders, investing them on capital markets, and paying out claims, taxes, and costs (see Brocket et al., 1998; also called flow approach; see Leverty/Grace, 2008). 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, 1985; Cummins/Weiss, 2000). The *value-added approach* (also called production approach; see Grace/Timme, 1992; Berger et al., 2000) counts outputs as important if they contribute a significant added value based on operating cost allocations (see Berger et al., 2000). 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 policyholders, and redistributing most of them to customers who have incurred losses. Via the second service, "real" financial services relating to insured losses, insurers create value added for their policyholders by providing real services such as financial planning (life) or the design of coverage programs (property-liability). The third service is intermediation; insurers create value added by acting as financial intermediaries that invest the premiums provided by the policyholders, e.g., on the capital market and pays out claims and administrative expenses (see, e.g., Cummins/Nini, 2002).

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., 2000). 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, 1993). 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/Weiss, 2000, 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 policyholders that incur losses. Thus, losses represent the total amount redistributed by the pool and are a useful risk proxy (see Berger et al., 2000). In life insurance, incurred benefits represent payments received by policyholders in the current year; they measure the amount of funds pooled by insurers and redistributed to policyholders 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 policyholders (in the case of asset accumulation products sold by life insurers) or are needed to pay claims (see Cummins/Weiss, 2000). Additions to reserves or invested assets are thus good proxies for the intermediation function and often used in literature (see, e.g., Berger et al., 2000; Cummins et al., 1999b). 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.

4.3. 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/Weiss (2000) 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 (1993) 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 recognizable trend over time as to whether either of the two main proxies is gaining more of a following among researchers.[3]

Since the value-added approach to output measurement dominates the literature, there have only been few innovations with regard to output measurement. Hwang/Kao (2008) 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, e.g., taking ROI, liquid assets to liability, and solvency scores as outputs (see Brockett et al., 2004, 2005).

A reflection of popularity is not necessarily an indication of validity. A good example is the controversial discussion in literature on value added versus financial intermediation (Brocket et al., 2005; Leverty/Grace, 2008). Cummins/Weiss (2000) argues that the financial intermediation approach is not optimal because insurers provide many services in addition to financial intermediation. Leverty/Grace (2008) 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 recognized as highly efficient have a higher proclivity to fail. In the light of these results it seems quite reasonable to prefer the value added approach over the financial intermediation.

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 insur-

[3] We categorized the number of studies by usage of output proxy and year of publication: from 1991 to 1995 3 studies use claims/benefits and 5 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.

ance industry (see Klumpes, 2007). Five studies use both the value-added and intermediation approaches (see, e.g., Jeng/Lai, 2005; Leverty/Grace, 2008). Two studies apply physical outputs, e.g., Toivanen (1997) uses number of product units produced as insurance output.

5. 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, organizational 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 analyze the 95 studies of our survey according to their field of application and selected main results. For this purpose, we consider 10 application categories (see Table 1). As a quick overview, Table 2 summarizes the main findings that are discussed in more detail below.

Insert Table 2 here

5.1. Distribution systems

Two main hypotheses have been developed to explain the coexistence of distribution systems in the insurance industry (see Berger/Cummins/Weiss, 1997). 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, e.g., 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, e.g., 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. (1998, 2004), studying the US, and Klumpes (2004), studying the United Kingdom, find that independent agent distribution systems are more efficient than direct systems involving company representatives or employed agents. Against it, Berger/Cummins/

Weiss (1997) find for the US that independent agent systems are less cost efficient, but equally profit efficient. On a more general level, Ward (2002) finds for the United Kingdom that insurers focusing on one distribution system are more efficient than those employing more than one mode of distribution. Trigo Gamarra/Growitsch (2008), in a study for German life insurance, finds that single line insurers are neither more cost nor more profit efficient than multichannel insurers.

5.2. Financial and risk management, capital utilization

Cummins et al. (2006) were the first to explicitly investigate the relationship between risk management, financial intermediation, and economic efficiency. In their application to the US property-liability industry, they analyze 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. (2004) 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 US property liability market. Cummins/Nini (2002) find for the same country and line of business, that large increases in capitalization between 1989 and 1999 represent an inefficiency in so far as equity capital is significantly over-utilized.

5.3. 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/Obijiaku, 2007), Tunisia (see Chaffai/Ouertani, 2002), Malaysia (see Mansor/Radam, 2000), or Australia (see Worthington/ Hurley, 2002). 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 with 75% cost efficiency on average have significant improve-

ment potential (see Bikker/van Leuvensteijn, 2008). The same is true for China with average technical efficiency of 77% in non-life and 70% in life (see Yao/Han/Feng, 2007), as well as Greece with average cost efficiency of 65% (see Noulas et al., 2001).

5.4. Intercountry comparisons

The first cross-country comparison was conducted by Weiss (1991). It covers the US, Germany, France, Switzerland, and Japan. She finds high productivity for the US and Germany. Japan shows the weakest productivity growth for the period 1975–1987. Rai (1996), in a broader cross-country study (11 OECD countries), concludes that firms in Finland and France have the highest efficiency and firms in the United Kingdom have the lowest. Donni/Fecher (1997) 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/Starkey/O'Brien (2002) find striking international differences in average efficiency. According to their study, insurers doing long-term business in the United Kingdom, 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/Grace/Skipper (2002) study efficiency and productivity in Asian insurance markets. Their results show increasing productivity in Korea and Philippines due to deregulation and liberalization, but liberalization 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 (2007) and Fenn et al. (2008). Fenn et al. (2008) find increasing returns to scale for the majority of EU insurers. The results indicate that mergers and acquisitions, fa-

cilitated by liberalized EU markets, have led to efficiency gains. Eling/Luhnen (2008) combine the AM Best US and Non-US database and conduct a cross-country comparison of insurers from 36 countries, 12 of which have not previously been analyzed 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 United Kingdom, where many studies have consistently indicated relatively low efficiency levels compared to other countries (around 60%; see Rai, 1996; Fenn et al., 2008; Vencappa/Fenn/Diacon, 2008). Diacon (2001), however, finds higher efficiency for the United Kingdom—77%, which is higher than that found for competiting European countries in their study. Given that most efficiency research so far focuses on the US, 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 US and for other insurance markets, e.g., considering the effect of different organizational forms on efficiency or considering economies of scale and scope.

5.5. Market structure

Choi/Weiss (2005, 2008) analyze three hypotheses derived from the industrial organization 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/Weiss (2005) 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/Weiss (2008) support the RMP hypothesis, implying that insurers in competitive and non-stringently regulated US 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. (2008), finding that larger firms with high market shares tend to be less cost efficient.

5.6. Mergers

Kim/Grace (1995) conduct a simulation analysis of efficiency gains from hypothetical horizontal mergers in the US life insurance industry. Their results indicate that most mergers would improve cost efficiencies, with the exception of mergers between large firms. Two other US studies (Cummins/Tennyson/Weiss (1999) for life insurance and Cummins/Xie (2008) for property-liability insurance) conclude that mergers are beneficial for the efficiency of acquiring and target firm. Klumpes (2007) tests the same hypothesis as Cummins/Tennyson/Weiss (1999) and Cummins/Xie (2008) for the European insurance market and finds that acquiring firms are more likely to be efficient than nonacquiring firms. However, he finds no evidence that target firms achieve greater efficiency gains than nontarget firms. Merger activity in the European insurance markets seems to be mainly driven by solvency objectives—i.e., financially weak insurers are bought by financially sound companies— and less by value maximization, as in the US.

5.7. Methodology issues, comparing different techniques or assumptions

A few studies primarily solve methodological issues or compare different techniques and assumptions over time. Cummins/Zi (1998) compare different frontier efficiency methods—DEA, DFA, FDH, SFA—and find that the efficiency results can differ significantly across these methods. Fuentes/Grifell-Tatjé/Perelman (2001) 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/Grace (2008) compare the value-added and intermediation approaches to efficiency measurement and find that these approaches are not consistent (see Section 3.1 and 3.2 for more details on methodology and techniques).

5.8. Organizational form, corporate governance issues

A well-developed field of frontier efficiency analysis deals with the effect of organizational form on performance. The two principal hypotheses in this area are the expense preference hypothesis (see Mester, 1991) and the managerial discretion hypotheses (see Mayers/Smith, 1988). 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 organizational forms use different technologies and that mutual companies are more efficient in lines of business with relatively low managerial discretion (see Cummins/Weiss, 2000).[4]

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 hypothesis (see, e.g., Cummins/Weiss/Zi, 1999 and Erhemjamts/Leverty, 2007 for the US market; Diboky/Ubl, 2007 for Germany). However, other studies have found mutuals more efficient than stocks. For example, Diacon/Starkey/O'Brien (2002), in a comparison of 15 European countries, find higher levels of technical efficiency for mutuals than for stocks. Also, Greene/Segal (2004) in an application to the US life insurance industry, suggest that mutual companies are as cost efficient as stock companies. Other studies investigate efficiency improvements after demutualization (see, e.g., Jeng/Lai/McNamara, 2007) and compare the efficiency of firms after initial public offerings versus that of private firms (see Xie, 2008). Looking at corporate governance issues, a positive relation between cost efficiency and the size of the corporate board of directors was identified (see Hardwick/Adams/Zou, 2004).

5.9. 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. (1999) find modest efficiency improvements from deregulation for the UK and German life insurance markets for the period from 1992–1994. Hussels/Ward (2006) 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 (2000) 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/Rubio-Misas (2006) 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/Grace/

[4] The hypotheses that stocks and mutuals use different technologies is also called efficient structure hypotheses (Cummins/Rubio-Misas/Zi., 2004; Wende et al., 2008), but this hypotheses is not related to the efficient structure hypotheses mentioned with the discussion of market structure in Section 5.5.

Skipper (2002) find evidence for productivity increases in Korea and the Philippines due to deregulation. Considering the US, Ryan/Schellhorn (2000) find unchanged efficiency levels from the start of the 1990s to the middle of that decade, a period during which risk-based capital requirements (RBC) became effective. Recently, Yuan/Phillips (2008) 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.

5.10. Scale and scope economies

Scale economies have been extensively researched in the context of consolidation and the justification of mergers (see Cummins/Weiss, 2000). Although detailed results vary 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., Hardwick, 1997, for UK, Hwang/Gao, 2005, for Ireland, Qiu/Chen, 2006, for China, and Fecher/Perelman/ Pestieau, 1991 for France). However, the differentiation between size clusters must be considered to achieve more specific results. For example, Yuengert (1993) finds increasing returns to scale for US life insurance firms with up to US$15 billion in assets and constant returns to scale for bigger firms. In contrast, Cummins/Zi (1998), 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 constant returns to scale.

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/Weiss/Zi, 2007). Considering US life insurers, Meador/Ryan/Schellhorn (2000) find that diversification across multiple insurance and investment product lines resulted in greater efficiency which is in line with the conglomeration hypothesis. Fuentes/Grifell-Tatjé/ Perelman (2005) also find evidence for economies of scope, in their case for Spanish life and non-life insurers. Berger et al. (2000) show for the US that profit scope economies are more likely to be realized by larger firms. In contrast to all these authors, Cummins/Weiss/Zi (2007) use cross-frontier analysis and find mixed results with regard to scope economies.

6. 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 analyze 95 studies on efficiency measurement in the insurance sector, provide a systematization 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.

Data envelopment analysis (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, e.g., the development of more appropriate functional forms for the econometric approaches or the introduction of bootstrapping procedures for the mathematical programming approaches. With 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 US-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. (2008) and Diacon et al. (2002)—or consider relatively small datasets—such as Rai (1996), which covers only 106 companies in 11 countries. In this context the relatively new research topics of market structure (see, e.g., Choi/Weiss, 2005, 2008) and risk management (see, e.g., Cummins et al., 2006) need to be analyzed for a

larger sample of countries. This would allow us to move away from the US 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 risk-based capital standards for insurers, such as Solvency II (see, e.g., Eling et al., 2007), 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 United States is also needed when it comes to analysis of mergers and efficiency. For example, all studies on this topic except for one (Klumpes, 2007) are US-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—e.g., auto insurance, as done by Choi/Weiss (2008) 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 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, i.e., for each business unit or line of business; the link between capital allocation in insurance companies that is controversially discussed in recent literature (Myers/Read, 2001; Gründl/Schmeiser, 2007) 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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Application	Country	Method	Author (Date)
Distribution systems	US	DFA	Berger et al. (1997)
	US	DEA	Brockett et al. (1998)
	US	DEA	Carr et al. (1999)
	UK	SFA	Klumpes (2004)
	Germany	DEA	Trigo Gamarra/Growitsch (2008)
	UK	SFA	Ward (2002)
Financial and risk management, capital utilization	US	DEA	Brockett et al. (2004a)
	US	SFA	Cummins et al. (2006)
	US	DEA	Cummins/Nini (2002)
General level of efficiency and evolution over time	Portugal	DEA	Barros et al. (2005)
	Nigeria	DEA	Barros/Obijiaku (2007)
	Netherlands	SFA	Bikker/van Leuvensteijn (2008)
	US	DEA	Cummins (1999)
	Tunisia	DEA, SFA	Chaffai/Ouertani (2002)
	Italy	DEA	Cummins et al. (1996)
	US	SFA	Cummins/Weiss (1993)
	France	DEA, SFA	Fecher et al. (1993)
	US	DFA	Gardner/Grace (1993)
	Taiwan	DFA	Hao (2007)
	Taiwan	DFA, SFA	Hao/Chou (2005)
	UK	SFA	Hardwick (1997)
	China	SFA	Huang (2007)
	Germany	DEA	Kessner/Polborn (1999)
	China	DEA	Leverty et al. (2004)
	Germany	DEA	Luhnen (2008)
	Malaysia	DEA	Mansor/Radam (2000)
	Greece	DEA	Noulas et al. (2001)
	China	DEA	Qiu/Chen (2006)
	India	DEA	Tone/Sahoo (2005)
	US	SFA	Weiss (1991a)
	Australia	DEA	Worthington/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/Fecher (1997)
	36 countries	DEA, SFA	Eling/Luhnen (2008)
	Germany, UK	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	US	SFA	Choi/Weiss (2005)
	US	SFA	Choi/Weiss (2008)
	14 European countries	SFA	Fenn et al. (2008)
Mergers	US	DEA	Cummins et al. (1999a)
	US	DEA	Cummins/Xie (2008)
	7 European countries	DEA	Davutyan/Klumpes (2008)
	US	DFA	Kim/Grace (1995)
	7 European countries	DEA	Klumpes (2007)

DEA: data envelopment analysis; DFA: distribution-free approach; FDH: free disposal hull; SFA: stochastic frontier approach; TFA: thick frontier approach

Table 1: Studies on efficiency in the insurance industry

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

DEA: data envelopment analysis; DFA: distribution-free approach; FDH: free disposal hull; SFA: stochastic frontier approach; TFA: thick frontier approach

Table 1: Studies on efficiency in the insurance industry (continued)

Application	Findings
Distribution systems	§ In most studies independent agent distribution systems are more efficient than direct systems (Brockett et al., 1998, 2004; Klumpes, 2004) § Insurers with one distribution system are more efficient than those employing more than one (Ward, 2002)
Financial and risk management, capital utilization	§ Risk management and financial intermediation increase efficiency (Cummins et al., 2006) § Solvency scores have limited impact on efficiency (Brockett et al., 2004)
General level of efficiency and evolution over time	§ Significant levels of inefficiency with corresponding room for improvement, e.g., for Nigeria, Tunisia, Malaysia
Intercountry comparisons	§ Striking international differences in average efficiency, e.g., Nigeria (see Barros/Obijiaku, 2007), Tunisia (see Chaffai/Ouertani, 2002), Malaysia (see Mansor/Radam, 2000), or Australia (see Worthington/ 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/Luhnen, 2008)
Market structure	§ More efficient firms charge lower prices than their competitors (Choi/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/Tennyson/Weiss (1999), Cummins/Xie, (2008) § Mergers and acquisitions, facilitated by the liberalized 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/Zi, 1998) § The value-added and intermediation approaches to efficiency measurement are not consistent (Leverty/Grace, 2008)
Organizational form, corporate governance issues	§ Most authors find that stock companies are more efficient than mutuals (Cummins/Weiss/Zi, 1999) § Efficiency improvements after demutualization were identified (Jeng/Lai/McNamara, 2007)
Regulation change	§ Modest efficiency improvements from deregulation in Europe (Rees et al., 1999, Hussels/Ward, 2006) § Efficiency gains in Asia due to deregulation (Boonyasai/Grace/Skipper, 2002) § No efficiency change with risk-based capital requirements implementation in the US (Ryan/Schellhorn, 2000)
Scale and scope economies	§ Increasing returns to scale for US firms with up to US$1 billion in assets (Cummins/Zi, 1998) § Mostly evidence for economies of scope, more recently mixed evidence (Cummins/Weiss/Zi, 2007)

Table 2: Main findings from the 95 studies

Appendix A: Overview of 95 Studies on efficiency measuremen

Authors	Countries	No. insu-rers	Sample period	Lines of business	Me-thod	Input type	Output type
Badunenko et al. (2006)	Ukraine	163	2003-2005	Life, non-life	DEA	Fixed assets, current assets, liabilities, equity	Premiums
Barros et al. (2005)	Portugal	27	1995-2001	Life, non-life	DEA	Wages, capital, total investment income, premiums issued	Claims paid, p
Barros and Obijiaku (2007)	Nigeria	10	2001-2005	Life, non-life	DEA	Capital, operative costs, number of employees, total investments	Profits, net pre claims, outsta investment inc
Berger et al. (2000)	US	684	1988-1992	Life, property-liability	TFA, SFA	Labor, business services, re-serves, financial equity capital	Invested asse of real losses incurred bene
Berger et al. (1997)	US	472	1981-1990	Property-liability	DFA	Labor, business services, debt capital, equity capital	Total real inve present value curred
Bernstein (1999)	Canada	12	1979-1989	Life	Cost func-tion	Labor, buildings capital, machinery capital, materials	Number of poi
Bikker and van Leuvensteijn (2008)	Nether-lands	84-105	1995-2003	Life	SFA	Acquisition cost, other cost (man-agement cost, salaries, depreciation on capital equipment, etc.)	Premium inco outstanding po of insured cap insured annuit fund policies
Boonyasai et al. (2002)	Korea, Philippines, Taiwan, Thailand	49-110	1978-1997	Life	DEA	Labor, capital, materials	Premium inco ment income
Brockett et al. (1998)	US	1524	1989	Property-liability	DEA	Surplus previous year, change in capital and surplus, underwriting and investment expense, policy-holder-supplied debt capital	ROI, liquid ass solvency scor
Brockett et al. (2004a)	US	1524	1989	Property-liability	DEA	Surplus previous year, change in capital and surplus, underwriting and investment expense, policy-holder-supplied debt capital	ROI, liquid ass solvency scor
Brockett et al. (2004b)	US	538	1995	Health	DEA	Premiums (consumer perspective), expenses (societal perspective)	Number of out number of hos member mont
Brockett et al. (2005)	US	1524	1989	Property-liability	DEA	Surplus previous year, change in capital and surplus, underwriting and investment expense, policy-holder-supplied debt capital	ROI, liquid ass solvency scor
Carr et al. (1999)	US	66	n/a	Life	DEA	Labor (admin., agents), business services, financial capital	Incurred bene reserves
Chaffai and Ouertani (2002)	Tunisia	13	1990-2000	Life, non-life	DEA, SFA	Labor, physical capital, financial capital	Total premium

Table A1: Overview of studies on efficiency in the insurance indus

Authors	Countries	No. insu-rers	Sample period	Lines of business	Me-thod	Input type	Output type
Choi and Weiss (2005)	US	n/a	1992-1998	Property-liability	SFA	Labor (agent, nonagent), materials, equity capital	Present value curred, total in
Choi and Weiss (2008)	US	n/a	1992-1998	Property-liability (auto)	SFA	Labor (agent, nonagent), materials, equity capital (assumed same as in Choi/Weiss, 2005, according to reference in paper; however, inputs not explicitly described in paper)	Present value curred, total in (assumed sam Choi/Weiss, 2 reference in p outputs not ex in paper)
Cummins (1999)	US	750	1988-1995	Life	DEA	Labor (admin., agents), business services, financial capital	Incurred bene reserves
Cummins et al. (2006)	US	1636	1995-2003	Property-liability	SFA	Labor (admin., agents, risk man-agement), material and business service, debt capital, equity capital	Present value curred, invest duration of su
Cummins and Nini (2002)	US	770-970	1993-1998	Property-liability	DEA	Labor (office, sales), materials and business service, financial equity capital	Present value curred, total in
Cummins and Rubio-Misas (2006)	Spain	331-508	1989-1998	Life, non-life	DEA	Labor, business services, debt capital, equity capital	Non-life losse losses incurre reserves, non reserves, inve
Cummins/Rubio-Misas/Zi (2004)	Spain	347	1989-1997	Life, non-life	DEA	Labor, business services, debt capital, equity capital	Life and non-l losses incurre
Cummins et al. (1999a)	US	750	1988-1995	Life	DEA	Home-office labor, agent labor, business services (including physical capital), financial capital	Incurred bene reserves
Cummins et al. (1996)	Italy	94	1985-1993	Life, non-life	DEA	Labor (acquisition, admin.), fixed capital expense, equity capital	Life insurance insurance ben reserves, inve Non-life insura incurred, inves
Cummins and Weiss (1993)	US	261	1980-1988	Property-liability	SFA	Labor, capital, intermediate mate-rials	Discounted in loss settlemen services
Cummins et al. (1999b)	US	417	1981-1990	Property-liability	DEA	Labor, materials, debt capital, equity capital	Present value incurred, total

Table A1: Overview of studies on efficiency in the insurance indus

Authors	Countries	No. insu-rers	Sample period	Lines of business	Me-thod	Input type	Output type
Cummins et al. (2007)	US	817	1993-1997	Life (incl. health), property-liability	DEA	Labor (office, agent), materials and business service, financial equity capital	Life/health: Re incurred bene reserves; P/L: Present v losses incurre assets
Cummins and Xie (2008)	US	1550	1994-2003	Property-liability	DEA	Labor (admin., agent), materials and business services, financial equity capital	Present value incurred, real
Cummins and Zi (1998)	US	445	1988-1992	Life	DEA, DFA, FDH, SFA	Labor, financial capital, materials	Benefit payme reserves
Davutyan and Klumpes (2008)	7 European countries	472	1996-2002	Life, non-life	DEA	Labor, business services, equity capital	Present value curred, premiu assets
Delhausse et al. (1995)	Belgium, France	434	1984-1988	Non-life	DEA, SFA	Labor costs, other outlays (capital consumption, purchase of equip-ment and supplies, etc.)	Premiums
Diacon (2001)	6 European countries	431	1999	General insurance	DEA	Total operating expenses, total capital, total technical reserves, total borrowings from creditors	Net earned pr investment inc
Diacon et al. (2002)	15 Euro-pean countries	454	1996-1999	Life incl. pension, and health	DEA	Total operating expenses, total capital, total technical reserves, total borrowings from creditors	Net earned pr investment inc
Diboky and Ubl (2007)	Germany	90	2002-2005	Life	DEA	Labor, business services, financial debt capital, equity capital	Gross premiu
Donni and Fecher (1997)	15 OECD countries	n/a	1983-1991	Life, non-life	DEA	Labor	Net premiums
Donni and Hamende (1993)	Belgium	300	1982-1988	Life, non-life	FDH	Labor cost, other cost	Premiums; alt incurred
Eling and Luhnen (2008)	36 coun-tries	6462	2002-2006	Life, non-life	DEA, SFA	Labor and business service, financial debt capital, equity capital	Non-life: claim reserves; Life additions to re ments

Table A1: Overview of studies on efficiency in the insurance indu

Authors	Countries	No. insu-rers	Sample period	Lines of business	Me-thod	Input type	Output type
Ennsfellner et al. (2004)	Austria	97-105	1994-1999	Life/ health, non-life	SFA	Net operating expenses, equity capital, technical provisions	Health/life: Inc changes in res invested asse Non-life: Loss invested asse
Erhemjamts and Leverty (2007)	US	1070	1995-2004	Life	DEA	Labor, business services, equity capital, policyholder-supplied debt capital	Incurred bene reserves
Fecher et al. (1993)	France	327	1984-1989	Life, non-life	DEA, SFA	Labor cost, other outlays	Gross premiu
Fecher et al. (1991)	France	327	1984-1989	Life, non-life	SFA	Labor cost, other outlays	Gross premiu
Fenn et al. (2008)	14 Euro-pean countries	n/a	1995-2001	Life, non-life, composite	SFA	Capital, technical provisions, labor, debt capital	Net incurred c claims paid – from reinsurer loss reserves rebates)
Fuentes et al. (2001)	Spain	55-70	1987-1994	Health, life, non-life	SFA	Labor costs, composite input	Annual premiu
Fuentes et al. (2005)	Spain	n/a	1987-1997	Health, life, property-liability	SFA	Labor costs, composite input	Annual premiu
Fukuyama (1997)	Japan	25	1988-1993	Life	DEA	Labor (office, sales), capital	Insurance res
Fukuyama and Weber (2001)	Japan	17	1983-1994	Non-life	DEA	Labor (office, sales), capital	Reserves, loa
Gardner and Grace (1993)	US	561	1985-1990	Life	DFA	Labor, physical capital, misc. items	Premiums, se ments
Grace and Timme (1992)	US	423	1987	Life	Cost func-tion	Labor, capital, misc. expenses	Premiums, an ments
Greene and Segal (2004)	US	136	1995-1998	Life	SFA	Labor, capital, materials	Premiums, inv
Hao (2007)	Taiwan	26	1981-2003	Life	DFA	Labor, physical capital, claims	Premiums, inv
Hao and Chou (2005)	Taiwan	26	1977-1999	Life	DFA, SFA	Labor, physical capital, claims	Premiums, inv

Table A1: Overview of studies on efficiency in the insurance indu

Authors	Countries	No. insu-rers	Sample period	Lines of business	Me-thod	Input type	Output type
Hardwick (1997)	UK	54	1989-1993	Life incl. pension, and health	SFA	Labor, capital	Premiums
Hardwick et al. (2004)	UK	50	1994-2001	Life	DEA	Labor, capital	Incurred bene reserves
Hirao and Inoue (2004)	Japan	33	1980-1995	Property-liability	SFA	Labor, agencies, materials	Real incurred claims paid ar loss reserves)
Huang (2007)	China	n/a	1999-2004	Life, property-liability	SFA	Labor, capital, business services	Premiums ear benefits and a reserves, total
Hussels and Ward (2006)	Germany and UK	47 (UK) 31 (GE)	1991-2002	Life	DEA, DFA	Labor, capital	Net written pre tions to reserv
Hwang and Gao (2005)	Ireland	11	1991-2000	Life	DFA	Labor (admin., agent), financial capital	Insurance ben funds
Hwang and Kao (2008a)	Taiwan	17	1999-2002	Non-life	DEA	Business and administrative expenses, commissions and acquisition expenses	1st stage: Dire premiums, rei miums 2nd stage: un income, inves
Hwang and Kao (2008b)	Taiwan	24	2001-2002	Non-life	DEA	Operation expenses, insurance expenses	1st stage: dire ums, reinsura 2nd stage: un income, inves
Jeng and Lai (2005)	Japan	19	1985-1994	Non-life	DEA	VA: Labor, business services, capital (debt + equity) FI: Surplus previous year/assets, change in surplus/assets, under-writing + investment ex-penses/assets, policyholder debt capital/assets	VA: Number o invested asse FI: ROA, 3 pri nents of finan
Jeng et al. (2007)	US	11	1980-1995	Life	DEA	VA: Labor, business services, capital (debt + equity) FI: Surplus previous year/assets, change in surplus/assets, under-writing + investment ex-penses/assets, policyholder debt capital/assets	VA: Number o invested asse FI: ROA, 3 pri nents of finan
Kessner (2001a)	Germany and UK	87 (UK) 78 (GE)	1994-1999	Life	DEA	New business cost, administration cost, cost for capital management, reinsurance contributions	Gross and net miums, interes
Kessner (2001b)	Germany	75	1989-1994	Life	DEA	New business cost, administration cost, cost for capital management, reinsurance contributions	Sum insured (business), net capital investm
Kessner and Polborn (1999)	Germany	110	1990-1993	Life	DEA	New business cost, administration cost	Sum insured o force business

Table A1: Overview of studies on efficiency in the insurance indu

Authors	Countries	No. insu-rers	Sample period	Lines of business	Me-thod	Input type	Output type
Kim and Grace (1995)	US	248	1988-1992	Life	DFA	Labor (agent, nonagent), capital, materials	Claims, chang investment ex
Klumpes (2004)	UK	40	1994-1999	Life	SFA	Labor, materials, policy supplied debt capital, financial equity capital	Claims, real in
Klumpes (2007)	7 European countries	1183	1997-2001	Life, general insurance	DEA	Labor, business services, debt capital, equity capital	Premiums, inv
Leverty and Grace (2008)	US	n/a	1989-2000	Property-liability	DEA	VA: Labor (admin, agent), mate-rials and business services, financial equity capital, policy-holder-supplied debt capital FI: Policyholder surplus, under-writing and investment expenses, policyholder-supplied debt capital	VA:Real losse invested asse FI: ROI, liquid liabilities, solv
Leverty et al. (2004)	China	20-41	1995-2002	Life, property-casualty	DEA	Business expenses, financial equity capital, debt capital	Life: Net prem invested asse P&C: Losses i invested asse
Luhnen (2008)	Germany	295	1995-2006	Property-liability	DEA	Labor and business service, financial debt capital, equity capital	claims incurre assets
Mahlberg (1999)	Austria and Germany	36 (AU) 118 (GE)	1992-1996	Life, health, property-liability	DEA	Administration and distribution cost (1 input)	Claims, chang refund of prem
Mahlberg (2000)	Germany	348	1992-1996	Life, health, property-liability	DEA	Administration and distribution cost (1 input)	Claims, chang refund of prem
Mahlberg and Url (2000)	Germany	464-533	1992-1996	Life, health, property-liability	DEA	Administration and distribution cost (1 input)	Claims, net ch sions, allocate returns, bonus premiums
Mahlberg and Url (2003)	Austria	59-70	1992-1999	Life, health, property-liability	DEA	Administration and distribution cost (1 input), cost of capital invest-ments	Claims, net ch sions, allocate returns, bonus premiums
Mansor and Radam (2000)	Malaysia	12	1987-1997	Life	DEA	Claims, commission, salaries, expenses, other cost	New policy iss policy in force
Meador et al. (2000)	US	358	1990-1995	Life	DFA	Labor, physical capital, misc. items	Premiums, se ments
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 produc-tion of services (1 input)	Premium inco from investme
Qiu and Chen (2006)	China	14-32	2000-2003	Life	DEA	Labor, equity capital, other	Benefit payme reserve, yield

Table A1: Overview of studies on efficiency in the insurance indu

Authors	Countries	No. insu-rers	Sample period	Lines of business	Me-thod	Input type	Output type
Rai (1996)	11 OECD countries	106	1988-1992	Life incl.health, non-life	DFA, SFA	Labor, capital, benefits and claims	Premiums (life
Rees et al. (1999)	Germany and UK	n/a	1992-1994	Life	DEA	Distribution cost, administration cost	Total premium change in tota income (UK), insured and cl gate sum insu
Ryan and Schellhorn (2000)	US	321	1990-1995	Life	DFA	Labor, financial capital, materials	Benefit payme reserves
Toivanen (1997)	Finland	21	1989-1991	Non-life	SFA	Labor	Number of uni
Tone and Sahoo (2005)	India	n/a	1982-2001	Life	DEA	Labor, business services, debt capital, equity capital	Present value incurred, ratio to liabilities
Trigo Gamarra (2008)	Germany		1995-2002	Life	SFA	Acquisition and administration expenses, equity capital	Incurred bene reserves, bon
Trigo Gamarra and Growitsch (2008)	Germany	115	1997-2005	Life	DEA	Acquisition and administration expenses, equity capital	Incurred bene reserves, bon
Turchetti and Daraio (2004)	Italy	45	1982-2000	Motor	DEA	Acquisition production and organi-zation cost, overhead and admin-istrative expenses, fixed capital, financial equity capital, policy-holder debt capital	Incurred losse assets
Vencappa et al. (2008)	14 Euro-pean countries	n/a	1995-2001	Life, non-life	SFA	Labor and materials, financial capital, debt capital	Incurred claim
Ward (2002)	UK	44	1990-1997	Life	SFA	Labor, capital	Claims, additi
Weiss (1986)	US	2	1976-1980	Life	Index	Labor (supervisor, agent, other); materials; capital (home office, field)	Number of pol dollar insuranc premium
Weiss (1991a)	US	100	1980-1984	Property-liability	SFA	Labor (agent, supervisory, nonsu-pervisory), material, capital	Incurred losse
Weiss (1991b)	France, Germany, Japan, Switzer-land, US	n/a	1975-1987	Property-liability	Index	Labor, capital	Incurred losse

Table A1: Overview of studies on efficiency in the insurance indu

Authors	Countries	No. insu-rers	Sample period	Lines of business	Me-thod	Input type	Output type
Wende at al. (2008)	Germany	40	1988-2005	Property-liability	DEA	Operating expenses, equity capital, debt capital	Claims incurre assets
Worthington and Hurley (2002)	Australia	46	1998	General insurance	DEA	Labor, information technology, physical capital, financial capital	Net premium r vested assets
Wu et al. (2007)	Canada	71-78	1996-1998	Life incl. health	DEA	Prod: Labor expenses, operating exp., capital equity, claims incurred Inv: Net actuarial reserves, invest-ment exp., total investments, total segregated funds	Prod: Net prer net income Inv: Investmer and mortgage gains in equiti
Wu et al. (2007)	Canada	71-78	1996-1998	Life incl. health	DEA	Prod: Labor expenses, general operating expenses, capital equity, claims incurred Inv: Net actuarial reserves, invest-ment expenses, total investments, total segregated funds	Prod: Net prer net income Inv: Investmer and mortgage gains in equiti estate
Xie (2008)	US	107	1993-2004	Property-liability	DEA	Labor, (admin, agent), business service and materials, financial equity capital	Present value curred, real in
Yang (2006)	Canada	72	1998	Life incl. health	DEA	Prod: Labor expenses, general operating expenses, capital equity, claims incurred Inv: Net actuarial reserves, invest-ment expenses, total investments, total segregated funds	Prod: Net prer net income Inv: Investmer and mortgage gains in equiti estate
Yao et al. (2007)	China	22	1999-2004	Life, non-life	DEA	Labor, capital, payment and benefits	Premiums, inv
Yuan and Phillips (2008)	US	613	2003-2005	life, property-liability, (commercial banks, thrifts)	SFA	Labor (admin, agent), material and physical capital, financial equity capital, debt capital	P/L: Present v losses incurre Life: Incurred additions to re
Yuengert (1993)	US	765	1989	Life incl. accident and health	SFA, TFA	Labor, physical capital	Reserves, add serves
Zanghieri (2008)	14 Euro-pean countries	n/a	1997-2006	Life, non-life	SFA	Labor, debt capital, equity capital	Claims paid, a reserves

Notations: DEA: data envelopment analysis; DFA: distribution-free approach; FDH: free disposal hull; SFA: stochastic fron
by Weiss (1986, 1991b), Grace and Timme (1992) and Bernstein (1999) are excluded from the overview, but included in t

Table A1: Overview of studies on efficiency in the insurance indus

Appendix B: Search Strategy

Our search strategy consists of four steps. Table 1 summarizes these four steps and their most important elements (called sub-steps in Table 1).

Number	Step	Sub-steps
1	Definition of the search strategy	1.1. Define a list of relevant key words (based on the Cummins/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: Geneva Papers on Risk and Insurance, 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 of the paper (authors, countries, no. 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 (see page 5 in the paper) 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 A2: Search Strategy

The first step was to define a search strategy based on a list of key words, journals and authors. In the second step we implemented the search strategy, i.e., 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 2. 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 analyze the found articles on a set of predefined criteria. This step resulted in the large Table presented in Appendix A of the paper. Here we also deleted articles that are not efficient frontier based, but focus on productivity or other aspects. We 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.

Key words / Journals	Efficiency	Productivity	Data Envelopment Analysis	Stochastic Frontier Analysis	…
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					
…					

Table A3: Matrix-like review strategy for journals