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FEATURE ARTICLE

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Analysis of insurers' performance using frontier efficiency and productivity methods. The great contributions by David Cummins and Mary Weiss

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Abstract

This article provides an in-depth analysis of the great contributions by J. David Cummins and Mary A. Weiss to research on insurers' performance using frontier efficiency and productivity methods. Twenty-nine empirical papers are surveyed as well as a book chapter that gives foundations and a guide in using methodology and defining outputs and inputs. Both econometric and non-parametric approaches have been used to estimate frontiers in these analyses, the data envelopment analysis (DEA) being the most frequently used method. A modified version of the value-added approach has normally been used to define outputs and inputs. The majority of their studies focus on the United States, but they have also conducted analyses on other countries (Germany, Italy, and Spain) as well as on intercountry samples (mainly European countries but also Islamic countries). Their empirical papers in this strand of literature have been grouped into 11 different application areas where the main analyzed issues and/or hypotheses tested as well as the principal

findings have been discussed. Their contributions to this field have received great attention in literature to the point that the leading paper in almost all of these application areas is one conducted by Cummins and/or Weiss.

1 | INTRODUCTION

The development of frontier methodologies for estimating efficiency and productivity as a type of benchmarking method constitutes an important advancement in modern economics. In the last four decades, the growth in frontier efficiency and productivity research has been explosive and these methodologies have become dominant for measuring the performance of firms and other types of decision-making units using accounting data. Not surprisingly, this growth has had important implications for insurance economics, since numerous studies require the comparison of insurance firms relative to other firms in the industry. J. David Cummins (henceforth Cummins) and Mary A. Weiss (henceforth Weiss) were pioneers in capturing the usefulness of these methodologies for the performance measurement in the insurance sector in such a way that this area is one of the most important of their research and they hold an undeniable leadership on it.

As stated in Cummins and Weiss (2000, 2013), Farrel (1957) developed the efficiency concepts building on the earlier work by Debreu (1951). Traditional micro-economic theory of the firm accepts that all firms minimize costs and maximize profits and that firms that do not succeed in achieving these objectives are not of interest because they will not survive (Cummins and Weiss, 2013). The modern frontier efficiency analysis started to build a framework in the 50s to analyze firms that do not succeed in optimization and, as a result, are not fully efficient (Farrell, 1957). This theoretical framework implies that efficiency is evaluated by comparing firms to "best practice" efficient frontiers composed of the most efficient firms in the reference set. However, it was not until the late 70s that methodologies for estimating efficiency were developed. The most important methodological contributions were the development of the stochastic frontier analysis (SFA) by Aigner et al. (1977), Battese and Corra (1977), and Meeusen and van den Broeck (1977) as well as the development of non-parametric mathematical programming frontiers by Charnes et al. (1978).

There are two main methodologies to estimate frontiers: (i) econometric approaches including the SFA (e.g., Greene, 2008). They generally make assumptions about the functional form of the technical, cost, revenue, or profit function and error term distributions and estimate efficiency using econometric techniques; and (ii) non-parametric approaches, the most outstanding being the data envelopment analysis (DEA), which do not make assumptions about functional forms. They estimate efficiency using linear programming and other non-parametric methods (see, e.g., Cooper et al., 2011). Both methodologies (econometric and non-parametric) have relative merits. The main advantage of the parametric approach is that firms are allowed to deviate from the frontier due to random error as well as inefficiency, whereas the non-parametric approaches measure all departures from the frontier as inefficiency. However, the parametric approach has the disadvantage that if wrong assumptions are made about the functional form and error term distributions, efficiency estimates can be confused by

specification errors. Yet, despite the advantages and disadvantages of these two methodologies, parametric and non-parametric approaches generally produce consistent results as Cummins and Zi (1998) showed in their analysis of the US life insurance industry.

Frontier efficiency methods can be used in a variety of ways (see Cummins and Weiss, 2013). Testing economic hypotheses represents one of their most important functions. A second important application is to provide a guidance to regulators and policymakers with regard to the appropriate response to problems and developments in an industry or the overall economy. A third function is to inform management about the effects of new strategies and technologies. The empirical contributions of Cummins and Weiss have covered all these main application areas. In addition, they have provided the foundations to insurance economists to adapt their research to incorporate the frontier efficiency approach. They have also provided guides in using methodology and defining inputs and outputs. Consequently, a paper on the contributions by Cummins and Weiss to the analysis of insurers' performance using frontier efficiency and productivity methods is important in a conference and a special issue in commemoration of their great contributions to research in risk management and insurance. Not only does this paper allow the recognition of Cummins and Weiss's advances in this area of research, but it will also be a guide for researchers who would like to start in this strand of insurance literature.

As stated above, they were pioneers in capturing the usefulness of frontier methodologies for the performance measurement in the insurance sector. Since then until this present day they have occupied a leadership position in this area of research as one could notice in the survey papers of this strand of literature. In extant literature, six papers have reviewed the studies on efficiency and productivity in the insurance industry using frontier efficiency methodologies: Berger and Humphrey (1997), Cummins and Weiss (2000, 2013), Eling and Luhnen (2010), Kaffash and Marra (2017), Kaffash et al. (2020). In all of them their leadership appears. For instance, the first review was carried out by Berger and Humphrey (1997). They surveyed eight papers on frontier efficiency in the insurance industry of which Cummins was the author of five and Weiss was the author of four. The last review was conducted by Kaffash et al. (2020) and included 132 DEA application studies in the insurance industry published from 1993 through July 2018. In this survey Kaffash et al. (2020) highlight that Cummins is the first author in terms of citations with 35.8% of them.

After this introduction, the rest of the paper is structured as follows: Section 2 shows a general discussion of the issues related to frontier efficiency and productivity of financial institutions; Section 3 presents an overview of Cummins and Weiss's contributions to the analysis of insurers' performance using frontier efficiency and productivity methods; Section 4 discusses the analyzed issues/tested hypotheses as well as the most important findings from their empirical studies to 11 different application areas; Section 5 provides a summary and conclusions.

2 | EVALUATING PERFORMANCE OF FINANCIAL INSTITUTIONS USING FRONTIER EFFICIENCY AND PRODUCTIVITY ANALYSIS

The first job in evaluating the performance of financial institutions using frontier efficiency and productivity analysis is to separate those production units that perform well from those that perform poorly. This is done by applying parametric or non-parametric techniques to firms

inside the financial industry or to branches inside a firm. Frontier analysis constitutes an advanced way to "benchmark" the relative performance of production units. It allows electing "best practice" firms inside the industry (or "best practice" branches inside the firm), to give numerical efficiency values, to recognize areas of input overuse and/or output under-production, and to connect these findings to questions of government policy or academic research (Berger & Humphrey, 1997). The information collected from using frontier analysis to evaluate the performance of financial institutions has been utilized in three main ways. One way has been to enhance managerial performance by recognizing "best practices" and "worst practices." Examples of applications on financial institutions conducted in this area are Sherman and Gold (1985) or Herrera-Restrepo et al. (2016). A second way of using this information has been to inform government policy by evaluating the effects of deregulation (e.g., Cummins & Rubio-Misas, 2006; Humphrey & Pulley, 1997; Sturm & Williams, 2004), market structure (e.g., Berger, 1995; Choi & Weiss, 2005; González, 2009), or mergers (e.g., Peristiani, 1997; Corcorese & Ferri, 2020; Cummins, Tennyson, & Weiss, 1999) on efficiency. A third way has been to deal with testing economic hypotheses (such as hypotheses on organizational forms). Examples of applications on financial institutions conducted in this area are Elyasiani and Mehdian (1992), Mester (1993), Cummins et al. (1999), or Mirzaei et al. (2022).

Because engineering information on the technology of financial institutions is not available, studies on frontier efficiency depend on accounting measures of outputs, inputs, costs, revenues, or profits to assign efficiency relative to the best practice inside the available sample (Berger & Humphrey, 1997). There are three main methods of choosing the outputs that financial institutions produce: financial intermediation, user cost, and value-added approaches (Berger & Humphrey, 1992). Under the financial intermediation approach, financial institutions are treated only as financial intermediaries between liability holders and those who receive funds from financial institutions. Concerning this approach to the banking industry, traditionally, loans, and other assets are considered to be bank outputs, while deposits and other liabilities are inputs to the intermediation process (see Sealey & Lindley, 1977). The user cost method decides whether a financial product is an input or output by its net contribution to the revenues of financial institutions. If a financial product yields a return that exceeds the opportunity cost of funds or if the financial cost of a liability is less than the opportunity cost, then the product is considered to be a financial output. Otherwise, it is considered a financial input (Hancock, 1985). Consequently, the user cost approach determines whether a bank asset or liability category is an output or an input depending on its net contributions to bank revenues. The value-added approach describes output as those activities that have significant value added as judged using operating cost allocations (see, e.g., Berger et al., 1987). The application of this approach in studies on the banking industry traditionally identifies the major categories of produced deposits (demand, time, and savings) and loans (real estate, commercial, installment) as important outputs because they are responsible for the great majority of value added (Berger & Humphrey, 1992). The value-added approach is argued by Berger and Humphrey (1992) as the best method for banks to evaluate performance using frontier efficiency and productivity analysis and the most used for measuring outputs in the banking industry.

Concerning these approaches to the insurance industry, the intermediation approach views insurers as pure financial intermediaries that borrow funds from policyholders, invest them on capital markets and pay out claims, taxes, and costs. As Cummins and Weiss (2013) claim, this approach is not likely to be suitable for either nonlife and life insurers because it could ignore

other services (e.g., insurance services) apart from intermediation services. Regarding the user cost approach, Cummins and Weiss (2013) discuss that this method is theoretically sound but it is difficult to use in practice since insurance policies bundle many services that are priced implicitly together. They considered that a modified version of the value-added approach is the most suitable method for studying insurance efficiency, also being the most utilized one.[1]

There is no consensus on the favorite method for deciding the best-practice frontier against which relative efficiencies of financial institutions are calculated. As stated above, there are two main approaches in the efficient frontier analysis: the econometric approach and the mathematical programming approach. The econometric approaches specify a production, cost, revenue, or profit function with a specific shape and usually make assumptions about the distributions of the inefficiency and error terms. There are three principal types of econometric frontier approaches: the stochastic frontier approach (SFA), the distribution-free approach (DFA), and the thick frontier approach (TFA). The 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 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. The 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 mathematical programming approaches put significantly less structure on the specification of the efficient frontier and do not decompose the efficiency and error terms. The DEA is the most used mathematical programming approach, which employs linear programming to measure the relationship of produced outputs to assigned inputs and determines the efficiency score as an optimization result. DEA models for estimating technical efficiency can be specified under the assumption of constant returns to scale (CRS), variable returns to scale (VRS), and nondecreasing returns to scale (NDRS). These models can be used to decompose technical efficiency into pure technical efficiency and scale efficiency as well as to estimate if the firm operates with constant, increasing or decreasing returns to scale.[2]

Different frontiers could be estimated, taking into account that the frontier is formed by the most efficient units of the reference set. The production frontier is the most basic efficient frontier. For its estimation, only output and input quantities are needed. However, if data on input (output) prices are available, one may estimate the cost (revenue and profit) frontier. While in estimating production and cost frontier, an input orientation is usually adopted, in estimating revenue and profit frontiers, an output orientation is normally followed. For instance, the production frontier is generally estimated based on the assumption that the firm is minimizing the input use, conditional on output levels. The cost frontier is normally estimated based on the assumption of cost minimization and involves choosing the optimal quantities of inputs to produce a given output vector. However, the revenue frontier is usually determined based on the assumption that the firm is maximizing revenues, conditional on inputs, and involves choosing the optimal quantities of outputs, conditional on the input vector. The profit frontier is also usually determined based on the assumption that the firm is maximizing profits and involves the optimal choice of inputs and outputs, conditional on output and input prices.

[1]Leverty and Grace (2010) show that the value-added approach is closely related to traditional measures of insurer performance and that efficient value-added approach firms are less likely to go insolvent.
[2]Cummins and Weiss (2013) provide an extensive discussion on the main frontier methodologies that have been developed to measure efficiency and productivity change over time.

The choice of input versus output orientation is based on the microeconomic theory establishing the firm's objective in maximizing profits by minimizing costs and maximizing revenues (Cummins and Weiss, 2013).

Efficiency is measured relative to the estimated *best practice frontiers*. It generally refers to the success of the firm in minimizing costs, maximizing revenues, or maximizing profits. The efficiency score is usually standardized between zero and one, with an efficiency score of one indicating fully efficient firm. However, profit efficiency is usually not constrained between zero and one. There are several concepts of efficiency. Technical efficiency is defined as the ratio of the input usage of a fully efficient firm producing the same output vector to the input usage by the analyzed firm. Cost efficiency for a specific firm is calculated as the ratio of costs of a fully efficient firm with the same output quantities and input prices to the specific firm's actual costs. Cost efficiency is the product of technical and input allocative efficiency. Thus, input allocative efficiency is the ratio of cost efficiency to technical efficiency and gives information on whether the firm uses the optimal mix of inputs. Revenue efficiency is defined as the ratio of the revenues of a specific firm to the revenues of a fully efficient firm with the same input vector and the same output prices. Revenue efficiency is the product of the output technical efficiency to the output allocative efficiency. Therefore, the output allocative efficiency can be calculated by the ratio revenue efficiency to output technical efficiency and gives information on whether the firm uses the optimal combination of outputs. Profit efficiency measures how close a firm gets to generating the maximum possible profits, given the input prices and output prices and their comparison with the best practice frontier (Cummins and Weiss, 2013).

In addition to efficiency, total factor productivity (TFP) is often analyzed in frontier efficiency studies to provide a dynamic analysis of performance. TFP is defined as an index of total quantity of output produced divided by an index of total inputs used (Fare et al., 2008). As stated in Cummins and Weiss (2013) the concept of TFP and efficiency are related. TFP is determined by the optimal production technology available to be employed in producing outputs as well as the efficiency with which firms use the technology. Consequently, TFP change has two major components: technical change and efficiency change. While technical change is given by a shift in the production frontier, efficiency change is given by an index of a firm's efficiency relative to the present and past frontiers. In general, TFP change can be estimated using both econometric approaches and mathematical programing approaches, the most frequent being the Malmquist index approach estimated using DEA.[3]

3 | OVERVIEW OF THE RESEARCH ON FRONTIER EFFICIENCY AND PRODUCTIVITY IN THE INSURANCE INDUSTRY CONDUCTED BY CUMMINS AND WEISS

This section provides a comprehensive survey of the research on efficiency and productivity in the insurance industry using frontier methodologies that has been carried out by Cummins and Weiss. I have identified 29 empirical papers on insurance efficiency and productivity studies that have been conducted by them from 1990 to 2022. Table 1 provides information for each

[3]Cummins and Weiss (2013) provide an ample discussion of the Malmquist index approach to analyze the TFP change of firms and its components over time.

TABLE 1 Empirical studies on efficiency and productivity in the insurance industry using frontier methods by J. David Cummins and Mary A. Weiss

Author	Country	Method	Frontier type	Type of institution	Sample period	No. of units/year	Type of publication
Weiss (1990)	USA	SFA	Cost	P-L	1980–1984	100	Article
Weiss (1991)	USA	SFA	Profit	P-L	1980–1984	100	Article
Cummins and Weiss (1993)	USA	SFA	Cost	P-L	1980–1988	261	Article
Berger et al. (1997)	USA	DFA	Cost/Profit	P-L	1981–1990	472	Article
Cummins et al. (1997)	Italy	DEA	Production	Life and P-L	1986–1993	94	WP
Cummins and Zi (1998)	USA	DEA/DFA/FDH/SFA	Cost	Life	1988–1992	455	Article
Cummins (1999)	USA	DEA	Production/Cost/Revenue	Life	1988–1995	750	Book chapter
Carr et al. (1999)	USA	DEA	Production/Cost/Revenue	Life	NA	NA	Book chapter
Cummins et al. (1999)	USA	DEA	Production/Cost/Revenue	Life	1988–1995	735	Article
Cummins et al. (1999)	USA	DEA	Production/Cost	P-L	1981–1990	417	Article
Berger et al. (2000)	USA	DFA	Cost/Revenue/Profit	Life and P-L	1988–1992	111/293/280	Article
Cummins & Nini (2002)	USA	DEA	Production/Cost/Revenue	P-L	1993–1998	644	Article
Cummins et al. (2004)	Spain	DEA	Production/Cost/Revenue	Life and nonlife	1989–1997	346	Article
Choi and Weiss (2005)	USA	SFA	Cost/Revenue	P-L	1992–1998	4777	Article
Cummins and Rubio-Misas (2006)	Spain	DEA	Production/Cost	Life and nonlife	1989–1998	382	Article

(Continues)

TABLE 1 (Continued)

Author	Country	Method	Frontier type	Type of institution	Sample period	No. of units/year	Type of publication
Weiss and Choi (2008)	USA	SFA	Cost/Revenue	P-L	1992–1992	1188	Article
Cummins and Xie (2008)	USA	DEA	Production/Cost/Revenue	P-L	1994–2003	1550	Article
Cummins and Xie (2009)	USA	DEA	Cost/Revenue	P-L	1995–2003	800	Article
Cummins et al. (2009)	USA	SFA	Cost	P-L	1995–2003	369	Article
Cummins et al. (2010)	USA	DEA	Cost/Revenue/Profit	Life and P/L	1993–2006	325/719	Article
Berry-Stölzle et al. (2011)	12 European countries	DEA	Cost/Revenue	P-L	2003–2007	691	WP
Cummins et al. (2012)	USA	DEA	Cost/Revenue/Profit	P-L	1993–2009	1338	WP
Cummins and Xie (2013)	USA	DEA	Production/Cost/Revenue	P-L	1993–2009	781	Article
Cummins and Xie (2016)	USA	DEA	Production/Cost/Revenue/Profit	P-L	1993–2011	768	Book chapter
Cummins and Rubio-Misas (2019)	Spain	DEA	Production/Cost/Revenue	Life and nonlife	1998–2010	NA	WP
David Cummins and Rubio-Misas (2021)	10 European countries	DEA	Cost/Revenue	Life	1998–2014	505	Article
Al-Amri, Cummins, and Weiss (2020)	19 Islamic countries	DEA	Production/Cost	Takaful	2004–2009	32	Article
Altuntas et al. (2021)	Germany	DEA	Production/Cost/Revenue	P-L	1999–2009	84	Article
Cummins and Rubio-Misas (2022)	10 European countries	DEA	Cost/Revenue	Life	1998–2014	505	Article

Abbreviations: DEA, data envelopment analysis; DFA, distribution-free approach; FDH, free disposal hull; P-L, property-liability; SFA, stochastic frontier analysis.

one of these papers on: (1) estimation methodology; (2) country or countries analyzed; (3) type of frontier estimated; (4) type of institution evaluated; (5) time-period covered by the sample; and (6) number of units per year analyzed. Table A1 shows the outputs, output prices, and inputs and input prices used in the surveyed studies. Table 2 summarizes these empirical studies in terms of the used methodology; journal where they were published; output utilized; coauthors; country or countries analyzed; year of publication. In addition to these 29 empirical papers, Cummins and Weiss have published a book chapter (the first edition in 2000 (Cummins & Weiss, 2000) and the second edition in 2013 (Cummins & Weiss, 2013) that involves a great contribution to this area of research. This book chapter is a basic reference for researchers on insurance efficiency and productivity applying frontier methodologies since it provides: (i) the foundations to incorporate the frontier efficiency approach in insurance economic research; (ii) a guide in using methodology and defining outputs and inputs; and (iii) a review of the empirical literature on efficiency and productivity measurement in insurance.

An important step to applying frontier methodologies to estimate insurer efficiency and productivity is the definition of outputs, inputs, and their prices. Cummins and Weiss (2000, 2013) have contributed to this key step significantly by providing the concept of insurance output from a theoretical perspective, defining insurance outputs and output prices in practice as well as inputs and input prices. As stated above, three are the main approaches to measure outputs and inputs in financial services—the intermediation approach, the user cost approach, and the value-added approach (Berger & Humphrey, 1992). Cummins and Weiss (2013) highlighted that a modified version of the value-added approach is the most suitable method for studying insurance efficiency, also being the most utilized one. The three main services in creating value for insurers under this approach are risk-pooling and risk-bearing services, real financial services related to insured losses, and intermediation services (Cummins and Weiss, 2013).

Cummins and Weiss (2013) claim that a satisfactory proxy for the amount of risk pooling/bearing and real insurance services is the value of real losses incurred for the nonlife insurance segment and real incurred benefits plus addition to reserves for the life insurance segment. They recommend using several output variables for the major lines of business offered by insurers in both cases (life segment and nonlife segment). They discuss that the most suitable output variable to proxy for the intermediation function is the real value of invested assets. In line with the unit price of insurance, they define the prices of the insurance output variables as premiums minus output divided by output, while the price for the intermediation output is defined by a measure of the expected rate of return on the insurer's assets. As stated before, Table A1 shows the outputs, output prices, inputs and input prices that Cummins and Weiss have used in their empirical studies. A summary of the outputs is also presented in Table 2. As expected, Cummins and Weiss have used the definition of outputs and output prices discussed in Cummins and Weiss (2013) when information was available. In fact we notice that most (27) of their empirical papers used real incurred losses and/or real incurred benefits as the insurance output measure as well as real invested assets (17 studies) as the intermediation output measure.

Within the context of the value-added approach, Cummins and Weiss stated that insurers use three primary inputs: labor, material and business services, and capital. We notice that in the surveyed studies labor and equity capital are the two most frequently utilized inputs since they are quantitatively quite important for insurers. However, sometimes two types of capital are considered: equity capital and debt capital (e.g., Berger et al., 2000; Cummins & Rubio-Misas, 2006). We also observe that, due to data unavailability, sometimes the labor input and

TABLE 2 Summary review of frontier efficiency and productivity studies in the insurance industry by Cummins and Weiss

Journal	No. of papers	Frontier type	No. of papers
Journal of Banking and Finance	6	Cost	27
Journal of Productivity Analysis	4	Revenue	19
Journal of Risk and Insurance	2	Production	14
Annals of Operations Research	2	Profit	6
Economic Analysis and Policy	1		
Journal of Business	1		
Journal of International Financial Markets Institutions and Money	1	Studies by year	
Journal of Financial Intermediation	1	1990	1
Journal of Financial Services Research	1	1991	1
Journal of Money Credit and Banking	1	1993	1
Management Science	1	1997	2
Managerial Finance	1	1998	1
Articles	22	1999	4
Working paper	4	2000	1
Book chapter	3	2002	1
Total	29	2004	1
		2005	1
Studies by methodology		2006	1
DEA	20	2008	2
SFA	6	2009	1
DFA	2	2010	1
DEA/DFA/FDH/SFA	1	2011	1
Studies by methodology (Cummins)		2012	1
DEA	19	2013	1
SFA	2	2016	1
DFA	2	2019	1
DEA/DFA/FDH/SFA	1	2021	3
Studies by methodology (Weiss)		2022	1
DEA	7		
SFA	5	Coauthor	
DFA	2	Al-Amri	1
DEA/DFA/FDH/SFA		Altuntas	1

TABLE 2 (Continued)

Journal	No. of papers	Frontier type	No. of papers
Studies by insurance segment		Berger	2
Life	6	Berry-Stölzle	2
Nonlife/P-L	16	Carr	1
Life and nonlife	6	Choi	2
Takaful	1	Dionne	1
Studies by insurance output		Feng	1
Losses/benefits	27	Gagne	1
Invested assets	17	Nini	1
Reserves	3	Nouria	1
Other	3	Regan	1
Studies by country		Rubio-Misas	5
USA	20	Tennyson	1
Spain	3	Turchetti	1
Germany	1	Wende	1
Italy	1	Xie	5
Multicountry	4	Zi	5

Abbreviations: DEA, data envelopment analysis; DFA, distribution-free approach; FDH, free disposal hull; SFA, stochastic frontier analysis.

the material and business services input are combined (e.g., Cummins & Rubio-Misas, 2022). Several indices are used as input prices: for instance, wage rate for labor, business services deflator for material and business services, the expected market return on equity capital for equity capital or a Treasury bill rate for debt capital. As physical measures of input quantities are usually not publicly available, the way to approach quantity of physical inputs is usually by dividing the expense item by a corresponding price index (Cummins and Weiss, 2013).

Table 2 also provides summary information of the type of frontier estimated in the surveyed papers. As stated above, the frontier is formed by the most efficient units of the reference set. Most papers have estimated more than one type of frontier, the cost frontier (with 27 studies) being the most estimated, followed by the revenue frontier (with 19 studies), the production frontier (with 14 studies), and the profit frontier (with 6 studies).

Table 2 summarizes the methodology used to measure efficiency and productivity change. We observe that the DEA approach has been the most frequently used methodology. Out of the 29 surveyed studies, 20 used DEA, 6 SFA, 2 DFA, and 1 considered multiple approaches from both the econometric and the mathematical programming sides. Nevertheless, we observe differences in terms of the methodology used between the research conducted by Cummins and Weiss. While the DEA approach has been the most frequently used methodology in Cummins's research (with 19 out of 24 studies), Weiss has used the mathematical and econometric approaches in the same proportion (50% of her studies used DEA and the other 50% used econometric approaches, mainly SFA).

Table 2 provides additional information. We observed that most surveyed papers focused on the nonlife segment. In fact, out of 29 reviewed studies, 16 focused on the nonlife segment, 6 on the life segment, 6 analyzed both segments, and 1 focused on Takaful (Islamic) insurers. In terms of the analyzed country, the majority of their studies focused on the United States, but Cummins and/or Weiss have/has also conducted analyses for Spain (3), Italy (1), and Germany (1). They have also carried out intercountry studies (three on European countries and one on Islamic countries). The 29 surveyed empirical papers consist of 22 published articles, 3 book chapters, and 4 working papers. The *Journal of Banking and Finance* is the outlet where many of the reviewed empirical articles have been published. Out of 22, 6 were published in the *Journal of Banking and Finance*, 4 in the *Journal of Productivity Analysis*, 2 in the *Journal of Risk and Insurance*, and 2 in the *Annals of Operations Research*. I also observe that Cummins and Weiss have been publishing regularly since 1990 to the present. Regarding coauthorship, out of the 29 reviewed empirical studies, Cummins is the author of 24 and Weiss of 14 and they coauthored 9 papers. They have also conducted their analyses with other researchers, María Rubio-Misas, Hongmin Zi and Xiaoying Xie being their main coauthors (in terms of the number of empirical papers) in their research on this strand of literature.

4 | MAIN ANALYZED TOPICS, HYPOTHESES, AND FINDINGS

This section discusses the main analyzed topics, hypotheses tested and principal findings of the empirical research conducted by Cummins and Weiss on insurers' performance using frontier efficiency and productivity methods. I have distinguished 11 different application areas. Some of them have been selected following the Berger and Humphrey (1997) overview as well as the surveys conducted by Cummins and Weiss (2000, 2013) and by Eling and Luhnen (2010). Although many studies make contributions to more than one topic, I tried to focus on the main fields of application. Table 3 provides information on the articles that conform the different topics by specifying the main issue analyzed and/or hypotheses tested as well as the principal findings.

4.1 | General level of efficiency

A first application of efficiency frontier methods was to evaluate the general level of efficiency in the insurance industry. I include two papers in this category. Weiss (1991) studied the cost impact resulting from United States P-L insurer inefficiency. She estimated a generalized Leontief profit function for 100 of the largest US P-L insurers over the period 1980–1984 using SFA. She found that estimated inefficiency costs were 12%–33% of premiums. Cummins and Weiss (1993) estimated stochastic cost frontiers for three size-stratified samples of US property-liability insurers over the period 1980–1988. They showed that large insurers operated in a narrow range around an average efficiency level of about 90% relative to their cost frontier. However, efficiency levels for medium and small insurers were about 80% and 88% in relation to their respective frontier. They also found that wider variations in efficiency were present for these two groups in comparison with large insurers.

TABLE 3 Topics analyzed, main hypotheses, and selected findings

Author	Issue/hypothesis	Selected findings
General level of efficiency		
Weiss (1991)	The cost impact resulting from P-L insurer inefficiency	Estimated inefficiency costs are 12%–33% of premiums
Cummins and Weiss (1993)	General level of efficiency for three size-stratified samples	Large insurers operate at 90% relative to their cost efficiency
		Efficiency levels for medium and small insurers are about 80% and 88% in relation to their respective frontier
Organizational form		
Cummins et al. (1997)	Comparison of stock and mutual efficiency	Mutuals have higher technical efficiency than stocks
Cummins and Zi (1998)	Expense preference versus efficiency sorting	Stock insurer efficiency is not greater than that of mutuals
Cummins et al. (1999)	Managerial discretion versus Expense preference	Stocks and mutuals have different technologies
		Mutuals less successful at minimizing costs
Cummins et al. (2004)	Efficiency structure versus Expense preference	Stocks and mutuals operate on separate cost and revenue frontiers
		Overall results consistent with efficient structure hypothesis
Al-Amri, Cummins and Weiss (2020)	Tests differences between the mudharaba (profit-sharing) and the wakala (fee-based) model	Profit-sharing model perform better than the fee-based model.
Mergers & acquisitions		
Cummins et al. (1999)	Effifiency of M&As targets	Acquired firms achieve greater efficiency gains that firms that have not been involved in M&As
	Returns to scale and acquisition	Acquirers prefer IRS and CRS firms
	Financial Strength and acquisition	Vulnerable firms are more likely to be acquired
	Group affiliation and acquisition	Unaffiliated firms are less likely to be acquired
Cummins and Rubio-Misas (2006)	Causes and effects of consolidation	Consolidation improved scale efficiency
	Financial strength and acquisition	Many small inefficient, and financially underperforming firms were eliminated from the market

(Continues)

TABLE 3 (Continued)

Author	Issue/hypothesis	Selected findings
Cummins and Xie (2008)	Examines efficiency and productivity changes for acquirers, targets, and non-M&A firms	M&As in P-L insurance is value enhancing
		Acquiring firms achieved more revenue efficiency gains than non-acquiring firms
		Target firms experienced greater cost and allocative efficiency growth than nontarget
	Firm factors associated with becoming an acquirer or target	Financially vulnerable insurers were more likely to become acquisition targets
Cummins and Xie (2009)	Determines relevance of efficiency scores	Efficient acquirers and targets have higher cumulative abnormal returns (CARs) but inefficient divesting firms have higher CARs
	Test hypotheses from corporate control production theory using market value data	Acquisitions and divestures were driven primarily by value-maximizing motivations
Cummins and Rubio-Misas (2019)	Role of insurer efficiency to be involved in M&As	Revenue efficiency positively influences parent of Spanish insurance group and subsidiaries of insurance group to become acquirer and target, respectively.
Distribution systems		
Berger et al. (1997)	Product quality versus Market imperfections	Independent agensts less cost efficient but equally profit efficient as direct writers. Support to product quality
Cummins (1998)	Insurance distribution system effect on efficiency	Brokerage system is most efficient on average
Carr, Cummins and Regan (1998)	Insurance distribution system effect on efficiency	Direct writers have a revenue (cost) efficiency advantage over insurers using agents (exclusive agents)
Cummins and Xie (2016)	Effect of different distribution systems on efficiency	Firms using direct writing distribution systems appear to be more efficient than these using agents and other distribution channels
Market structure		
Cummins and Nini (2002)	Investigating if capital utilization is a response to changing market conditions or an inefficiency	Most insurers over-utilized equity capital, leading to significant revenue penalties for inefficient firms
Choi and Weiss (2005)	Testing the Structure-Conduct-Performance (SCP), Relative	Support efficient structure hypothesis

TABLE 3 (Continued)

Author	Issue/hypothesis	Selected findings
	Market Power (RMP), and Efficient Structure (ES) hypotheses	
Weiss and Choi (2008)	Impact of regulation on state automobile US insurance industry. Testing the SCP, RMP and ES hypotheses for competitive versus regulated states	None hypothesis was supported for stringently regulated states. RMP is supported in competitive and non-stringently regulated states
Berry-Stölzle et al. (2011)	Testing the SCP, RMP, and ES hypotheses	Results strongly support the efficient structure hypothesis
Scale and scope economies		
Cummins and Weiss (1993)	Scale economies	Mild scale diseconomies for large insurers and potentially large-scale economies for smaller insurers
Cummins and Zi (1998)	Scale economies	Majority of firms are operating at either increasing or decreasing return to scale
Cummins (1998)	Scale economies	Most large firms face DRS; about 20% of firms operate with CRS
Cummins et al. (1999)	Scale economies	IRS to $billion assets, then DRS, CRS for some firms of all sizes
Berger et al. (2000)	Conglomeration versus strategic focus	Conglomeration dominates for some types of firms (e.g., large, emphasize personal lines). Strategic focus dominates for other types (e.g., small, emphasize commercial lines)
Cummins and Rubio-Misas (2006)	Scale economies	Insurance operations for Spanish firms are subject to ranges of production characterized by IRS
Cummins et al. (2010)	Conglomeration versus strategic focus	P-L insurers realize cost scope economies but they are more than offset by revenue scope des-economies. L-H insurers realize both cost and revenue scope des-economies
Cummins and Xie (2013)	Scale economies	Majority of firms below median size are operating with IRS. Majority of firms above median size are operating with DRS. A significant number of firms in each size decile achieved CRS. More diversified firms achieved efficiency and productivity gains
Al-Amri, Cummins, and Weiss (2020)	Conglomeration versus strategic focus	Strategic focus is superior to diversification for takaful in terms of efficiency

(Continues)

TABLE 3 (Continued)

Author	Issue/hypothesis	Selected findings
Regulatory change		
Cummins and Rubio-Misas (2006)	The effect of deregulation from EU's Third Generation Directives on efficiency	Unit prices declined in Life and nonlife; average firm size increased. Many small, inefficient and financially underperforming firms were eliminated from the market
Cummins and Rubio-Misas (2022)	Integration and convergence in efficiency and technology gap	Convergence in cost and revenue efficiency Convergence in meta-technology cost (revenue) efficiency. Financial crisis affected negatively convergence in cost efficiency and meta-technology cost efficiency, but not in terms of revenue efficiency
Risk management		
Cummins et al. (2009)	Test whether risk management and financial intermediation enhance cost efficiency	Risk management and financial intermediation enhance cost efficiency of P-L insurers
Cummins et al. (2012)	Relationship between firm performance and reinsurance utilization	Reinsurance utilization is positively related to cost, revenue, and profit efficiency. However, a performance penalty exists for reinsurance concentration
Altuntas et al. (2021)	Tests if enterprise risk management (ERM) facilitates economies of scale and scope	ERM facilitates economies of scale and economies of scope with respect to revenue complementarities
Intercountry studies		
Berry-Stölzle et al. (2011)	Efficiency in the P-L insurance industry of 12 European countries	Average cost (revenue) efficiency of groups of firms was 0.37 (0.49)
David Cummins and Rubio-Misas (2021)	Tests the role of financial market development and institutional quality on the integration of EU life insurance markets	National stock market development and institutional quality enhances cost performance and integration of EU life insurance markets Better outcomes in national institutional quality decrease the meta-technology revenue efficiency ratio.
Al-Amri, Cummins, and Weiss (2020)	Efficiency of takaful firms in 19 countries	Average cost efficiency of takaful with wakala model (mudharaba model) was 0.5470 (0.5125).
Cummins and Rubio-Misas (2022)	Comparison of technology gaps among EU countries	The UK and Germany show lower cost and revenue technology gap

TABLE 3 (Continued)

Author	Issue/hypothesis	Selected findings
Productivity analysis		
Weiss (1990)	Productuvity change	Productivity increased overall for the studied time period
Cummins et al. (1997)	Productivity change and components	A cumulative productivity declined of 25% attributable to technological regress
Cummins et al. (1999)	Productivity change and components	Acquired firms achieve greater efficiency gains that firms no involved in M&As
Cummins and Rubio-Misas (2006)	Productivity change and components	Productivity improved during the sample period attributed to gains in pure technical efficiency
Cummins and Xie (2008)	Productivity change and components	TFP growth is significantly lower for unaffiliated insurers than for groups
Cummins and Xie (2013)	Productivity change and components	Significant gains in TFP. Higher technology investment is positively related to efficiency and productivity improvements.
Cummins and Xie (2016)	Productivity change and components	Significant gains in productivity and efficiency
Methodology issues		
Cummins and Zi (1998)	Comparing a wide range of econometric and mathematical programing approach	The choice of estimation method can have a significant effect on the conclusions of an efficiency study
Cummins et al. (1999)	New approach (DEA cross-frontier analysis) for estimating the relative efficiency of alternative organizational forms	Stocks and mutuals are operating on separate production and cost frontiers
Berger et al. (2000)	New methodology to measure scope economies	Traditional methods to measure scope misleading
Cummins et al. (2009)	Test whether risk management and financial intermediation enhance cost efficiency	Shadow prices for risk management and financial intermediation estimated
Cummins and Rubio-Misas (2022)	Test the suitability of using the meta-frontier framework	Presence of heterogeneity in production possibility sets among countries

Abbreviations: CAR, cumulative abnormal returns; CRS, constant returns to scale; DRS, decreasing returns to scale; EU, European Union; IRS, increasing returns to scale; M&A, mergers and acquisitions; P-L, property-liability; TFP, total factor productivity.

4.2 | Organizational form

The effect of organizational form on performance is a well-developed field of research within the frontier efficiency analysis in the insurance industry, since two types of organizational forms coexist in a large number of countries: stocks that are owned by stockholders and

mutuals that are owned by customers, the policyholders. Two most prominent hypotheses have been developed in this area: the *efficient structure hypothesis* and the *expense preference hypothesis*. The *efficient structure hypothesis* claims the two organizational forms are sorted into market segments where they have comparative advantages in minimizing costs and maximizing revenues due to differences in managerial discretion, maturity and access to capital (see Mayers & Smith, 1988). This argument predicts that stocks will be more successful in lines that require more managerial discretion (such as complex lines), while mutuals are expected to be more successful in lines that require less managerial discretion (such as standardized lines). However, the *expense preference hypothesis* states that mutuals will be less successful than stocks in minimizing costs and maximizing revenues due to unresolved agency conflicts, since the available mechanisms for controlling owner-manager conflicts are relatively weak in mutuals (see Mester, 1989). These hypotheses are not mutually exclusive and mutuals could be more successful in low managerial discretion lines even though mutual managers exhibit expense preference behavior (Cummins et al., 1999).

We select papers where organizational form is a main issue in this section. Nevertheless, this firm characteristic has been taken into account in most frontier efficiency analyses conducted by Cummins and/or Weiss. The above mentioned hypotheses were first tested by simply including a dummy variable to distinguish between stocks and mutuals. This was the case of the papers by Cummins et al. (1997) and Cummins and Zi (1998) in their analyses of the Italian and the US life insurance industry, respectively, where they found mixed results. While Cummins et al. (1997) showed that mutuals had higher technical efficiency than stocks, Cummins and Zi (1998) found that the efficiency of stocks was not greater than that of mutuals.

There is a leading study by Cummins et al. (1999) on the organizational form topic, where stocks and mutuals of the property-liability US insurance industry were evaluated. This paper was the first in using the DEA cross-frontier analysis to test the *efficient structure hypothesis* and the *expense preference hypothesis*.[4] The analysis involves estimating the efficiency of the firms in each group not only with respect to a reference frontier consisting only of firms from its own group but also with respect to the other group's frontier. This allows calculating cross-to-own efficiency ratios, which measure the distance between the stock and mutual frontiers. They found that stocks and mutuals have different technologies, supporting the *managerial discretion hypothesis*. However, they also found that mutuals were less successful in minimizing costs than stocks in support of the *expense preference hypothesis*. Posteriorly, Cummins et al. (2004) also applied the DEA cross-frontier methodology in testing these two hypotheses on the Spanish stock and mutual insurers. They found that stocks and mutuals operate on separate cost and revenue frontiers. However, their overall results were consistent with the *efficient structure hypothesis*.

Recently, Al-Amri, Cummins, and Weiss (2020) have tested the differences in performance between the two major takaful organizational forms—the *mudharaba* (profit-sharing) and the *wakala* (fee-based) models for compensating managers in a sample of takaful (Islamic insurance) firms belonging to 19 different countries. The profit-sharing model is hypothesized to be more effective in aligning the incentives of managers and policyholders. The results show

[4]From then to now, several papers have used the DEA cross-frontier methodology to test economic hypotheses that address the coexistence of stock and mutual insurers (for a comprehensive analysis of the cross-frontier analysis, including a survey of the insurance literature on organizational form using frontier efficiency analysis, see Rubio-Misas and Gómez (2015).

that profit-sharing takaful firms are significantly more (cost, technical, scale) efficient than fee-based takaful firms.

4.3 | Mergers and acquisitions

Another application of frontier efficiency analysis in insurance is to investigate the efficiency effects of mergers and acquisitions (M&As) as well as the influence of efficiency in the insurer's chance to be involved in M&As. The Cummins, Tennyson, and Weiss (1997) paper is probably the leading contribution in this strand of literature, in view of the number of citations. They analyze the efficiency effects of M&As in the US life insurance industry over the period 1988–1995 by estimating cost and revenue efficiency using DEA as well as TFP using the Malmquist analysis. They found that acquiring firms achieve greater efficiency gains than a control group of insurers not involved in M&As. They further found that acquirers tend to acquire firms operating with NDRS. Later, Cummins and Rubio-Misas (2006) evaluated the causes and effects of consolidation in the Spanish insurance industry over the period 1989–1998 using the modern frontier efficiency analysis. They estimated cost, technical, scale, and allocative efficiency using DEA as well as TFP using the Malmquist analysis. They found that consolidation improved scale efficiency. Cummins and Xie (2008) analyzed the productivity and efficiency effects of M&As in the US property-liability insurance industry during the period 1994–2003 using DEA and Malmquist productivity indices. They also examined the firm characteristics associated with becoming an acquirer or target. The results supported that M&As were value-enhancing. Target firms experienced greater cost and allocative efficiency growth than non-targets and acquiring firms achieved more revenue efficiency gains than non-acquiring firms. Furthermore, consistent with the corporate control theory, financially vulnerable insurers were significantly more likely to become acquisition targets.

Cummins and Xie (2009) evaluated the market value relevance of efficiency scores, being one of the few papers in literature that relates insurer efficiency to market values. In doing so, they first estimated efficiency for the US P-L insurance industry over the period 1995–2003. Then, they evaluated the market response to P-L insurer acquisitions and divestures (A&Ds). They found that acquirers, targets, and divesting firms had significant abnormal returns around announcements dates. They also found that efficient acquirers and targets had higher cumulative abnormal returns (CAR) and inefficient divesting firms had higher CARs, suggesting that A&Ds were driven primarily by value-maximizing motivations. Recently, Cummins and Rubio-Misas (2019) have evaluated the role of insurer efficiency to be involved in M&As (either as target or acquirer) and if this role differs by ownership type in the Spanish insurance industry over the period 2000–2012. They estimated cost efficiency, revenue efficiency, and their components using DEA. They found that revenue efficiency positively influenced parents of Spanish insurance groups and subsidiaries of insurance groups to become acquirers and targets, respectively, suggesting that a competitive advantage in generating revenue is key to be involved in M&As.

4.4 | Distribution systems

The effect of distribution systems on efficiency has been analyzed in several studies conducted by Cummins and/or Weiss, the most representative being the Berger et al. (1997) paper. In this

study, they tested the *product-quality* hypothesis versus the *market-imperfection* hypothesis to explain the coexistence of independent-agency insurers and direct-writing insurers in the US property-liability insurance market, since independent-agency insurers are known to have higher costs. While the *product-quality* hypothesis maintains that the higher costs of independent-agency insurers are due to providing higher product quality or greater service intensity, which is compensated by higher revenues, the *market-imperfection* hypothesis states that these two types of insurers coexist due to market imperfections (impediments to competition). They measured cost efficiency and profit efficiency using the DFA introduced by Schmidt and Sickles (1984) and modified by Berger (1993). They found strong support to the *product quality* hypothesis, implying that independent-agency insurers produced higher quality outputs and were compensated by higher revenues.

Nevertheless, the empirical evidence on this issue provided in other studies conducted by Cummins are mixed. Cummins (1999) and Carr et al. (1999) used DEA to estimate efficiency in the US life insurance industry and evaluated the effect of the utilized distribution system on insurer efficiency. The results by Cummins (1999) show that the brokerage system is most (technical, cost, revenue) efficient on the average. Carr et al. (1999) found that direct writers have a revenue efficiency advantage over insurers using agents and have a cost efficiency advantage over firms using exclusive agents. Later, Cummins and Xie (2016) analyzed the US property-liability insurance industry over the period 1993–2011, comparing the effect of the different distribution systems on efficiency. In doing so, they estimated technical, pure technical, scale, cost, revenue, and profit efficiency using DEA and TFP, using the Malmquist analysis. Their results showed that firms using direct writing distribution systems appeared to be more efficient than those using agents and other distribution channels.

4.5 | Market structure

Four studies out of 29 surveyed papers investigated various aspects of market structure. Given the dramatic increase in the capitalization levels of the US property-liability insurance industry during the 1990s, Cummins and Nini (2002) investigated the use of capital by US property-liability insurers over the period 1993–1998. They aimed to provide evidence on whether the capital increase represented a response to change in market conditions or a true inefficiency that led to performance penalties for insurers. They estimated technical, cost, and revenue efficiency using DEA. Their results showed that most insurers over-utilized equity capital during the sample period and that capital over-utilization primarily represented an inefficiency for which insurers incurred in revenue penalties.

Choi and Weiss (2005) analyzed the relationships between market structure and performance in the US property-liability insurance industry over the period 1992–1998. They estimated cost efficiency and revenue efficiency using the SFA and tested three hypotheses derived from industrial organization literature: (i) the traditional *structure-conduct-performance* (SCP) hypothesis, which maintains that increased market concentration leads to higher prices and profits through increased possibilities for collusion among firms, because concentration lowers the cost of collusion; the *relative market power* hypothesis, which establishes that if consumers rely on a firm's position in the market as an indicator of quality, large firms may exercise market power due to their position in the market, allowing them to earn rents. Consequently, these two hypotheses provide arguments for antitrust regulation; and (iii) the *efficient structure* (ES) hypothesis, which maintains that the structure of the market in which a

firm operates is also determined by efficiency. It claims that more efficient firms charge lower prices than their competitors and still earn economic rents allowing them to capture large market shares, leading to increased market concentration. Therefore, according to the ES hypothesis, higher market concentration may benefit both firms and consumers. Their results supported the ES hypothesis and suggested that regulators should be more concerned about efficiency (both cost and revenue) rather than the market power that arises from consolidation activity.

Weiss and Choi (2008) investigated the impact of regulation on state automobile US insurance markets over the period 1992–1998 and analyzed the above-mentioned three hypotheses from industrial organization literature using SFA. None of these hypotheses were supported in stringently regulated states. However, they found that the RMP hypothesis was supported in competitive and non-stringently regulated states because they found a positive relationship between market share and price in these states. Nevertheless, firms in those states were, on average, more cost efficient and cost-efficient insurers charged lower prices and earned smaller profits. A further contribution to the topic of market structure with a focus on the EU has been made by Berry-Stölzle et al. (2011). They tested the SCP, RMP, and ES hypotheses and analyzed Nonlife insurers in 12 European countries over the period 2003–2007 by estimating efficiency using DEA. Their results strongly support the *efficient structure* hypothesis but provide little or no support for SCP and RMP hypotheses.

4.6 | Scale and scope economies

Scale economies are a main analyzed topic in the context of frontier efficiency analysis, particularly in the justification of mergers. Economies of scale exist if the average cost per unit of output declines as the volume of output increases. We focus on the papers conducted by Cummins and/or Weiss that have estimated scale economies as a primary objective of the paper in this study. Cummins and Zi (1998) analyzed scale economies using the DEA approach in the US life insurance industry over the period 1988–1992. They found that most of the insurers in the sample displayed either increasing or decreasing returns to scale and only about 6% of the firms were attaining CRS. Cummins (1999) evaluated scale economies in the US life insurance industry over the period 1988–1995 using DEA. Results showed that most relatively small insurers were operating with increasing returns to scale (IRS) and that most relatively large insurers were operating with decreasing returns to scale (DRS). Cummins et al. (1999), in their analysis of the US life insurance industry, found that firms operating with nondecreasing returns to scale (NDRS) were more likely to be acquisition targets. Cummins and Rubio-Misas (2006) analyzed scale economies in the Spanish insurance industry over the period 1989–1998 using DEA. They found that insurance operations for Spanish firms were subject to ranges of production characterized by IRS, permitting some insurers to reduce unit cost by increasing production. Cummins and Xie (2013) provided an extensive analysis of scale economies by analyzing the US property-liability insurance industry over the period 1993–2009 utilizing DEA. They found that the majority of insurers in the six smallest size deciles operated with IRS while the majority of insurers in the four largest deciles operated with DRS. The results also show that in every size decile at least 6% of insurers operated with CRS, indicating that it is possible to realize CRS even for large insurers.

Economies of scope are another essential aspect in industrial organizations.[5] The two principal hypotheses regarding scope economies are the *conglomeration* hypothesis and the *strategic focus* hypothesis. The *conglomeration* hypothesis maintains that operating a diversity of business can add value by exploiting cost and revenue scope economies. The *strategic focus* hypothesis holds that firms can best add value by focusing on core business. Berger et al. (2000) studied scope economies across the life and P-L segments of the US insurance industry over the period 1988–1992. They estimated cost, revenue, and profit functions using DFA to estimate efficiency and the concept of *profit scope economies* that measures the relative efficiency of joint versus specialized productions, taking both costs and revenues into account. The results showed that the *conglomeration* hypothesis dominated for some types of firms (large, emphasized personal lines of business, use of vertical integration systems) while the *strategic focus* hypothesis dominated for other types (small, emphasized commercial lines, use of nonintegrated distribution systems). This fact may explain why both joint producers and specialists appeared to be competitively viable in the long run.

Cummins et al. (2010) tested the *conglomeration* and the *strategic focus* hypotheses in the US insurance industry over the period 1993–2006. They estimated technical, cost, revenue, and profit efficiency using DEA. The results showed that P-L insurers realized cost scope economies, but they were more than offset by revenue scope diseconomies. Life-health insurers realized both cost and revenue scope economies. Therefore, they concluded that strategic focus was superior to conglomeration in the US insurance industry. Al-Amri, Cummins, and Weiss (2020) analyzed takaful firms in 19 countries and tested the two main hypotheses regarding scope economies. They estimated efficiency using DEA and found that the *strategic focus* was superior to *conglomeration* for takaful in terms of efficiency.

4.7 | Regulatory change

The effects of regulatory changes on efficiency have particularly been analyzed in two articles: Cummins and Rubio-Misas (2006) and Cummins and Rubio-Misas (2022). Cummins and Rubio-Misas (2006) analyzed deregulation, consolidation, and efficiency in the Spanish insurance industry over the period 1989–1998, spanning the introduction of the EU Third Generation Directives, which deregulated the EU insurance market. They estimated efficiency (technical, cost, allocative, scale, pure technical) and economies of scale using DEA as well as TFP and their components, using the Malmquist analysis. They found that deregulation had a dramatic impact on the Spanish insurance market. The number of firms declined by 35%, the average firm size increased by 275%, and the unit prices declined significantly in both life and nonlife insurance. Many small, inefficient, and financially underperforming firms were eliminated from the market due to insolvency or liquidation. As a result, the market experienced significant growth in TFP over the sample period.

Cummins and Rubio-Misas (2022) analyzed integration and convergence in efficiency and technology gap of 10 EU life insurance markets over the period 1998–2014. They evaluated whether the regulatory steps taken to promote integration among EU insurance markets led to a convergence in efficiency and technology gaps in those markets. They applied the meta-frontier DEA approach to estimate both efficiency and technology gap and the main concepts of

[5]A detailed definition of scope economies is discussed in Cummins and Weiss (2000, 2013).

convergence from economic growth literature, β-convergence and σ-convergence in the analysis. The results showed convergence in cost/revenue efficiency among major EU life insurance markets during the sample period. They also found convergence in cost/revenue technology gap among these markets, indicating that they became more technologically homogeneous during the sample period. However, the results indicated that the global financial crisis led to a slowdown in the progress of integration and convergence in efficiency and technology gap of EU life insurance markets in terms of cost efficiency but not in terms of revenue efficiency.

4.8 | Risk management

Frontier efficiency analysis has also been applied to gauge the effects of firm risk management strategies. Cummins et al. (2009) were the first to investigate the relationship between risk management, financial intermediation, and economic efficiency. They analyzed the US property-liability insurance industry over the period 1995-2003 and estimated efficiency using SFA. They considered risk management and financial intermediation activities as intermediate outputs and estimated their shadow prices. The econometric results showed that both activities significantly increased the efficiency of the property-liability insurance industry. Cummins et al. (2012) studied the US property-liability insurance industry over the period 1993–2009 and analyzed the relationship between performance and reinsurance utilization. They estimated efficiency (cost, revenue, and profit) using DEA. The results showed that reinsurance utilization was positively related to efficiency (especially with foreign reinsurers), indicating that reinsurance was an efficiency risk management device for P-L insurers. However, results showed that efficiency was adversely related to concentration in reinsurance counterparties.

Recently, Altuntas et al. (2021) have analyzed whether the use of the enterprise risk management (ERM) approach helps firms to achieve economies of scale and scope in the German property-liability insurance industry over the period 1999–2009. They estimated scale and scope economies using DEA and used detailed survey data of German property-liability insurers to construct continuous measures of ERM quality. They found that ERM quality moderated both the size-scale efficiency relationship and the diversification-revenue scope efficiency relationship, positively. These findings indicate that ERM facilitates economies of scale and economies of scope with respect to cost complementarities, suggesting that ERM creates value through its impact on economies of scale and scope.

4.9 | Intercountry studies

Cummins and/or Weiss conducted four intercountry studies where frontier efficiency methods were used: Berry-Stölzle et al. (2011); David Cummins and Rubio-Misas (2021); Al-Amri, Cummins and Weiss (2020); and Cummins and Rubio-Misas (2022). Three out of four papers were included in other categories since they involved another main issue in addition to the intercountry comparison. However, the David Cummins and Rubio-Misas (2021) paper was not included in any other categories because the main analysis focused on the extant differences among the analyzed countries with respect to some factors. More precisely, David Cummins and Rubio-Misas (2021) evaluated the role that national financial market development and institutional quality played in the integration of EU life insurance markets. They analyzed 10

EU life insurance markets over a 17-year sample period and used the meta-technology cost/revenue efficiency ratios, estimated under the meta-frontier DEA framework as a measure of integration. The results showed that national stock market development and institutional quality enhanced cost performance and integration of EU life insurance markets. They also found that in countries where *bancassurance* was the main life insurance distribution channel, banking sector development contributed to integration in terms of revenue efficiency. However, results also showed that better outcomes in national institutional quality decreased the meta-technology revenue efficiency ratio, suggesting that life insurance prices were lower in countries with better institutions.

4.10 | Total factor productivity

As stated above, TFP is often analyzed in frontier efficiency studies to provide a dynamic analysis of performance. Cummins and/or Weiss have estimated TFP change in seven papers. Six out of them have used the DEA Malmquist approach and one the SFA approach (Weiss, 1990). Most of them have focused on the US insurance industry (5), but there is also a paper on the Italian insurance industry and another one on the Spanish insurance industry. Most studies have focused on estimating the evolution of TFP change and its components over the period analyzed.

4.11 | Methodological issues

Several papers made a methodological contribution in addition to contributing to other empirical areas. This was the case of the Cummins and Zi (1998) paper that compared a wide range of econometric and mathematical programing techniques (DEA, DFA, FDH, SFA) for a sample of US life insurers.[6] They found that average efficiencies differed significantly across methods. The efficiency rankings were well preserved among the econometric methods but less well preserved between the econometric and mathematical programming methods and likewise between the DEA and FDH methods. Both the econometric and mathematical programming efficiency scores were significantly correlated with conventional performance measures, but the correlation tended to be higher for the mathematical programing methods.

Cummins et al. (1999) introduced the DEA cross-frontier analysis to estimate the relative efficiency of alternative organizational forms in an industry. They first provided evidence that stocks and mutuals were operating on separate production and cost frontiers, indicating that they represented distinct technologies. Following this, they applied the DEA cross-frontier analysis that involved measuring the relative efficiency of each organizational form by computing the efficiency of each stock (mutual) firm relative to a reference set consisting of all mutual (stock) firms. Berger et al. (2000) introduced a new method to estimate scope economies that differed from the traditional approach to estimating them. The traditional approach involves using a single continuous cost, revenue, or profit function that is estimated only for joint producers, but it is assumed to apply to specialists as well. However, this method

[6]The free disposal hull (FDH) approach is a special configuration of DEA where the convexity assumption on the efficient frontier is relaxed.

involves estimating separate functions, using only data from specialists to evaluate the performance of specialists and similarly use only data on joint producers to evaluate the performance of joint producers. This allows for the possibility that joint producers and specialists use different technologies. In addition, they estimated separate cost, revenue, and profit functions for the life insurance and P-L insurance division for joint producers, which avoided imposing symmetry artificially and allowed for the exclusion of irrelevant variables. Cummins et al. (2009) innovated by treating risk management and financial intermediation as endogenous in their econometric model. Then, because these activities are not observable, they were considered intermediate outputs and the authors estimated their shadow prices. The econometric estimation of the cost function that enabled estimating these shadow prices implied an important contribution of the paper. Recently, Cummins and Rubio-Misas (2022) tested the suitability of using of the DEA meta-frontier framework for a sample of 10 European countries. The results confirmed the presence of heterogeneity in production possibility sets among countries and, thus, that the use of the DEA meta-frontier framework was appropriate.

5 | SUMMARY AND CONCLUSIONS

This article provides an in-depth study of the research conducted by J. David Cummins and Mary A. Weiss on the analysis of insurers' performance using frontier efficiency and productivity methods. Their first papers in this area date from the early 90s, being pioneers in applying these methodologies in the insurance industry. Since then until the present day, they have been publishing leading papers in this field regularly, becoming key references for those of us who work in this area and for those who want to get started in it. Twenty-nine empirical papers as well as a book chapter (Cummins & Weiss, 2000, 2013) have been surveyed.

These empirical papers represent significant contributions to 11 application areas. One area consists of papers where the general level of efficiency is mainly evaluated. The organizational form area includes papers that usually test the *efficient structur*e and the *expense preference* hypotheses. In the mergers and acquisitions area, papers used to analyze the efficiency effects of M&As as well as the influence of efficiency in insurers' chance to be involved in M&As. Papers in the distribution systems area evaluate the effects of different distribution channels on efficiency and/or test the *product quality* versus the *market imperfections* hypotheses. The market structure area involves issues such as investigating the use of capital as well as testing the traditional *structure-conduct-performance*, the *relative market power* and the *efficient structure* hypotheses. The scale and scope economies topic involves papers where the effect of one of these aspects in industrial organization on efficiency is analyzed. In the context of scope economies, the *conglomeration versus* the *strategic focus* hypotheses are tested. In the regulatory change area, issues such as the effect on efficiency of the deregulation of EU insurance market are analyzed. Papers included in the risk management area involve testing whether risk management and financial intermediation enhance cost efficiency, analyzing the relationship between reinsurance utilization and firm performance or testing if ERM facilitates economies of scale and scope. Four papers are included in the intercountry studies topic including one that tests the role of financial market development and institutional quality on the integration of EU life insurance markets. Several papers provide a dynamic analysis of performance by studying TFP change and its components that are estimated using frontier methods. The methodology area includes articles that, in addition to contributing to other areas of research, compare different techniques over time or solve methodological issues.

Considering the literature on efficiency and productivity in the insurance industry using frontier methodologies, I have to highlight that, in general, in almost all of these application areas of research, the leading paper is one conducted by Cummins and/or Weiss in view of the attention that the paper receives in literature. In this sense, the five papers by Cummins and/or Weiss on the analysis of insurers' performance using frontier efficiency and productivity methods that have received more attention in literature (in terms of Google Scholar citations in October 2022) are: "Consolidation and efficiency in the US life insurance industry" by Cummins et al. (1999); "Measuring Economic Efficiency of the US life insurance industry: econometric and mathematical programming techniques" by Cummins and Zi (1998); "Organizational form and efficiency: An analysis of stock and mutual property-liability insurers" by Cummins et al. (1999); "The Coexistence of Multiple Distribution Systems for Financial Services: The Case of Property-Liability Insurance" by Berger, Cummins, and Weiss (1997); and "Deregulation, Consolidation and Efficiency: Evidence from the Spanish Insurance Industry" by Cummins and Rubio-Misas (2006). Additionally, the referred book chapter (with almost 500 Google Scholar citations in October 2022) has been and continues being an excellent and easy guide to provide foundations to incorporate the frontier efficiency approach in insurance economic, particularly for Ph.D. students and young researchers.

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APPENDIX A

TABLE A1 Outputs, output prices, inputs, and input prices.

Author	Output quantity	Output price	Input type	Input quantity	Input pice
Weiss (1990)	Incurred losses/ Claims cost index		Labor	Real value of labor expense	Price index for labor
	All policyholder reserves		Materials	Real value of material expense	Weigted average of price indexes for different types of intermediate goods
			Capital	Real value of capital	Market rate for $\beta = 1$
Weiss (1991)	Incurred losses/ claims cost index	(Premiums −Incurred losses)/ output volume	Labor		National Avg Wage Deflator for SIC 6331
	All policyholder reserves	3-month Treasury bill rate	Materials		Weighted Expense Deflator for other non labor expenses
			Capital		Net income/Financial Capital
Cummins and Weiss (1993)	Real incurred losses		Financial capital		Net income/Financial Capital
	Extrapolated loss adjustment expenses		Labor		Deflator for insurance wages SIC 6331

TABLE A1 (Continued)

Author	Output quantity	Output price	Input type	Input quantity	Input pice
	Real policyholder reserves		Business services		Deflator for Business Services SIC 7300
Berger et al. (1997)	Present value of real losses incurred	(Real premium-output volume)/ output volume	Labor	Total labor expense/Input price	Weighted average wage index for SCI 6331
	Total real invested assets	Expected rate of return on assets	Business services	All non-labor expense/Input price	Weighted average wage index for SCI 7399
			Debt capital	Loss reserves and unearned premium reserves	
			Equity capital	Surplus	
Cummins et al. (1997)	Value of real losses incurred		Acquisition labor	Acquisition expenses/Input price	Weigted average salary and rental deflator
	Incurred benefits plus changes in reserves		Administrative labor	Managerial and administrative labor expenses/Input price	Business services price deflator
	Total invested assets		Fixed capital	Fixed capital asset/Input price	Weighted average computer and real estate deflator
			Equity capital	Surplus/GDP deflator	GDP deflator

(Continues)

TABLE A1 (Continued)

Author	Output quantity	Output price	Input type	Input quantity	Input pice
Cummins and Zi (1998)	Real incurred benefits Real addition to reserves		Labor	Total labor expense/Input price	Average weekly wages SIC 6311
			Financial capital	Real surplus	3-year moving average net income to equity capital
			Materials	All non-labor expense/Input price	Weigted average composite index fomed by 11 component indices
Cummins (1999)	Incurred benefits plus addition to reserves	(Premiums + investment income −output volume)/ output volume	Administrative labor	Total administrative labor expenses/Input price	Weighted average wage index for SCI 6331
			Agent labor	Total agent labor expenses/ Input price	Weighted average wage index for SCI 6411
			Business services	Total business service expenses/Input price	Weighted average wage index for SCI 7300
			Financial capital	Equity capital	3-tier approach based on financial ratings assigned by the A.M. Best Company
Cummins et al. (1999)	Incurred benefits + addition to reserves	(Premiums + investment income) −output	Home office labor	Total home office labor expenses/Input price	Average weekly wage index for SCI 6331

TABLE A1 (Continued)

Author	Output quantity	Output price	Input type	Input quantity	Input pice
		volume/ output volume			
			Agent labor	Total agent labor expenses/ Input price	Weighted average wage index for SCI 6411
			Business services	Intermediate Expenses/Input price	Average weekly wage index for SCI 7300
			Financial capital	Surplus	3-tier approach based on financial ratings assined by the A.M. Best Company
Cummins et al. (1999)	Present value of real losses incurred		Labor	Labor expenses/Input price	Average weekly wage index for SCI 6331
	Real total invested assets		Business services	Non labor expenses/Input price	Average weekly wage index for SCI 7300
			Debt capital	Real loss reserves and unearned premium reserves	Investment income attribute to PH/Input volume
			Equity capital	Surplus	Expected net income/ Average value of surplus
Berger et al. (2000)	Present value of real losses incurred		Labor		Real average weekly wage index for SCI 6331

(Continues)

TABLE A1 (Continued)

Author	Output quantity	Output price	Input type	Input quantity	Input pice
	Real Incurred benefits		Business services		Real average weekly wage index for SCI 7300
	Real Invested assets		Debt capital	Real Reserves	Fixed netput
			Equity capital	Real Surplus	Fixed netput
Cummins & Nini (2002)	Present value of real losses incurred	(Premiums −Output volume)/ Output volume	Administrative Labor	Total Expenditure on administrative labor/price of labor	Real average weekly wage index for SCI 6331
	Average real invested assets	Expected rate of return on assets	Agent labor	Total expenditure on agent labor/price of labor	Weighted average wage index for SCI 6411
			Material and business services	Total material and business services expenses/Input price	
			Financial capital	Real Equity capital	90-day Treasury bill rate at the end of the preceding year plus the long-term market risk premium on large firm stocks
Cummins et al. (2004)	Losses incurred	(Nonlife premiums plus investment income	Labor	Labor expenses/Input price	Average monthly wage for employees in the insurance sector

TABLE A1 (Continued)

Author	Output quantity	Output price	Input type	Input quantity	Input pice
		−output volume)/ Output volume			
	Benefits incurred	(Life premiums plus investment income −Output volume)/ Output volume	Business services	Business service expenses/ Input price	Business services price deflator
			Financial debt capital	Debt capital	One-year Spanish Threasury bill rate
			Equity capital	Equity capital	Average rate of total return on the Madrid Stock Exchange Index
Choi and Weiss (2005)	Present value of real losses incurred	(Premiums −Output volume)/ Output volume	Agents' services	Agents' service expense	Weighted average wage index for SCI 6411
			Nonagent labor services	Nonagent labor service expense	Real average weekly wage index for SCI 6331
			Materials	Material expense	Real average weekly wage index for SCI 7300

(Continues)

TABLE A1 (Continued)

Author	Output quantity	Output price	Input type	Input quantity	Input pice
			Equity capital	Equity capital	Expected ROE for regressions analysis
Cummins and Rubio-Misas (2006)	Losses incurred		Labor	Labor expenses/Input price	Average monthly wage for employees in the insurance sector
	Benefits incurred		Business services	Business service expenses/ Input price	Business services price deflator
	Real value of reinsurance reserves		Financial debt capital	Borrowed funds and deposits from reinsurers	One-year Spanish Threasury bill rate
	Real value of reserves for primary insurance contracts		Equity capital	Financial Equity capital	Average rate of total return on the Madrid Stock Exchange Index
	Real value of invested assets				
Weiss and Choi (2008)	Present value of real losses incurred	(Premiums −Output volume)/ Output volume	Agents' services	Agents' service expense	Weighted average wage index for SCI 6411
			Nonagent labor services	Nonagent labor service expense	Real average weekly wage index for SCI 6331

TABLE A1 (Continued)

Author	Output quantity	Output price	Input type	Input quantity	Input pice
			Materials	Material expense	Real average weekly wage index for SCI 7300
			Equity capital	Equity capital	Expected ROE for regressions analysis
Cummins and Xie (2008)	Real present value losses incurred (some smothing)	(Premiums −Output volume)/ Output volume	Administrative Labor	Total Expenditure on administrative labor/price of labor	Average weekly wage index for SCI 6331
	Real Invested assets	Weigted average exp. Return on equities & realized ROR for other assets	Agent labor	Total Expenditure on agent labor/price of labor	Average weekly wage index for SCI 6411
			Material and business services	Total material and business services expenses/Input price	Weighted avg. of prices indices for business services for expenses components from Best's Aggregates & Averages
			Financial capital	Real equity capital	300 day Threasury bill rate at the end of the preceding year plus the long-term market risk premium on large firm stocks plus size premium

(Continues)

TABLE A1 (Continued)

Author	Output quantity	Output price	Input type	Input quantity	Input pice
Cummins and Xie (2009)	Real present value losses incurred (some smoothing)	(Premiums −Output volume)/ Output volume	Administrative Labor	Total Expenditure on administrative labor/price of labor	Average weekly wage index for SCI 6331
	Real Invested assets	Weigted average exp. Return on equities & realized ROR for other assets	Agent labor	Total Expenditure on agent labor/price of labor	Average weekly wage index for SCI 6411
			Material and business services	Total material and business services expenses/Input price	Weighted avg. of prices indices for business services for expenses components from Best's Aggregates & Averages
			Financial capital	Real equity capital	30-day Threasury bill rate at the end of the preceding year plus the long-term market risk premium on large firm stocks plus size premium
Cummins et al. (2009)	Present value of incurred losses	(Premiums earned− output volume)/	Administrative labor		Average weekly wage index for SCI 6331

TABLE A1 (Continued)

Author	Output quantity	Output price	Input type	Input quantity	Input pice
		output volume			
	Intermediation (intermediate output)		Agent labor		Average weekly wage index for SCI 6411
	Risk management (intermediate output)		Risk labor		Average weekly wage index for SCI 52392
			Material and business services		Average weekly wage index for SCI 7300
			Debt capital		Required return by policyholder, given insurer credit quality and liability duration
			Equity capital		Required return for listed insurers based on Fama-French 3 factor model
Cummins et al. (2010)	Incurred benefits plus addition to reserves	Premiums plus investment income −output volume/ output volume	Administrative labor	Total Expenditure on administrative labor/price of labor	Average weekly wage index for SCI 524113 for L-H insurers and 524126 for P-L insurers

(Continues)

TABLE A1 (Continued)

Author	Output quantity	Output price	Input type	Input quantity	Input pice
	Present value of real losses incurred	Premiums −output volume/ output volume	Agent labor	Total expenditure on agent labor/price of labor	Average weekly wage index for SCI 524210
	Average invested assets	Expected rate of return on assets	Material and business services	Total material and business services expenses/Input price	Weighted avg. of prices indices for business services for nonwage expenses
			Financial capital	Equity capital	30- day Threasury bill rate at the end of the preceding year plus the long-term market risk premium on large firm stocks plus size premium
Berry-Stölzle et al. (2011)	Real total losses incurred net of reinsurance	Real premiums earned −output volume/ output volume	Labor	Management expenses/Input price	Index of average wages for commissions and salaries in insurance companies
	Total invested assets	Realized investment income/ average invested assets	Business services	Acquisition expenses/Input price	Index of average costs of work for services except public services

TABLE A1 (Continued)

Author	Output quantity	Output price	Input type	Input quantity	Input pice
			Materials	Other expnses/Input price	OECD Production and Sales index
			Equity capital	Real value of surplus	Insurer's expected return on equity
			Debt capital	Technical provisions net of reinsurance	Short-term risk free rate
Cummins et al. (2012)	Present value of real losses incurred	Premiums −output volume/ output volume	Administrative labor	Total Expenditure on administrative labor/price of labor	Average weekly wage for SCI 524126
	Average real invested assets	Expected rate of return on assets	Agent labor	Total Expenditure on agent labor/price of labor	Average weekly wage for SCI 524210
			Material and business services	Total material and business services expenses/Input price	Weighted average of the national production price indices for materials and service items
			Financial capital	Real value of surplus	30- day Threasury bill rate at the end of the preceding year plus the long-term market risk premium on large firm stocks plus size premium

(Continues)

TABLE A1 (Continued)

Author	Output quantity	Output price	Input type	Input quantity	Input pice
Cummins and Xie (2013)	Real present value of losses incurred (smoothed)	(Premiums earned−output volume)/output volume	Administrative labor	Total Expenditure on administrative labor/price of labor	National average weekly wage rate for SIC 6331
	Average invested assets	Weighted average of expected return on stocks plus expected return on interest-bearing assets	Agent labor	Total Expenditure on agent labor/price of labor	National average weekly wage rate for SIC 6411
			Material and business services	Total material and business services expenses/Input price	Weighted avg. of prices indices for business services for expenses components from Best's Aggregates & Averages
			Financial capital	Real average value of surplus	Fama-French three factor cost of capital estimated for traded insurers, assigned to non-traded based on Best's ratings

TABLE A1 (Continued)

Author	Output quantity	Output price	Input type	Input quantity	Input pice
Cummins and Xie (2016)	Present value of real losses incurred	Premiums −output volume/ output volume	Administrative labor	Total Expenditure on administrative labor/price of labor	National average weekly wage rate for SIC 6331 which became NAICS 524126 since 2001
	Average real invested assets	Expected rate of return on assets	Agent labor	Total Expenditure on agent labor/price of labor	National average weekly wage rate for SIC 6411 which became NAICS 524210 since 2001
			Material and business services	Total material and business services expenses/Input price	Weighted avg. of prices indices for business services for expenses components from Best's Aggregates &Averages
			Financial capital	Real average value of surplus	Fama-French three factor cost of capital estimated for traded insurers, assigned to non-traded based on Best's ratings
Cummins and Rubio-Misas (2019)	Value of real losses incurred	(Premiums plus investment income −output volume)/ output volume	Equity capital	Equity capital	Average rate of total return on the Madrid Stock Exchange Index

(Continues)

TABLE A1 (Continued)

Author	Output quantity	Output price	Input type	Input quantity	Input pice
			Debt capital	Debt capital	One-year Spanish Threasury bill rate
			Business services	Total business service expenses/Input price	Average montly wage for employees in the Spanish insurance sector
David Cummins and Rubio-Misas (2021)	Value of real incurred benefits plus addition to reserves	Premiums −output volume/ output volume	Operating expenses	Operating expenses/Input price	Eurostat Index based on wages and salaries
	Real value of invested assets	Net investment income to invested assets	Debt capital	Debt capital	OECD 10-year-Threasury-Bill rates of the specific country.
			Equity capital	Surplus	20-year rolling average of the yearly rates of return of the country specific MSCI stock market indices
Al-Amri, Cummins and Weiss (2020)	Premiums		Labor		Operating expenses/Number of employees
	Total investment		Equity capital		Expected rate of return on the stock market of each country by year.
			Technical provisions		Each country's annual rate of interest on lending

TABLE A1 (Continued)

Author	Output quantity	Output price	Input type	Input quantity	Input pice
Altuntas et al. (2021)	Present value of losses incurred net of reinsurance	Real premiums earned −output volume/ output volume	Labor and business services	Operating expenses/Input price	German census bureau's index for insurance business services (BI index)
	Total invested assets	Realized investment income return for the year	Equity capital	Book value of surplus	Insurer's expected return on equity
			Debt capital	Technical provisions net of reinsurance	Two-to-three-year German Treasury Bill rates
Cummins and Rubio-Misas (2022)	Value of real incurred benefits plus addition to reserves	Premiums - output volume/ output volume	Operating expenses	Operating expenses/Input price	Eurostat Index based on wages and salaries
	Real value of invested assets	Net investment income to invested assets	Debt capital	Debt capital	OECD 10-year-Threasury-Bill rates of the specific country
			Equity capital	Policyholders' surplus	20-year rolling average of the yearly rates of return of the country specific MSCI stock market indices