Data Envelopment Analysis in Financial services: A Citations Network Analysis of Banks, Insurance Companies and Money Market Funds

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Abstract

Development and application of the Data Envelopment Analysis (DEA) method, have been the subject of numerous reviews. In this paper, we consider the papers that apply DEA methods specifically to financial services, or which use financial services data to experiment with a newly introduced DEA model. We examine 620 papers published in journals indexed in the Web of Science database, from 1985 to April 2016. We analyse the sample applying citations network analysis.

This paper investigates the DEA method and its applications in financial services. We analyse the diffusion of DEA in three sub-samples: (1) banking groups, (2) money market funds, and (3) insurance groups by identifying the main paths, that is, the main flows of the ideas underlying each area of research. This allows us to highlight the main approaches, models and efficiency types used in each research areas. No unique methodological preference emerges within these areas. Innovations in the DEA methodologies (network models, slacks based models, directional distance models and Nash bargaining game) clearly dominate recent research.

For each subsample, we describe the geographical distribution of these studies, and provide some basic statistics related to the most active journals and scholars.

Keywords: Data Envelopment Analysis, financial services, literature survey, citation analysis, main path analysis.

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1. Introduction

Data Envelopment Analysis (DEA) is a nonlinear programming model introduced by Charnes, Cooper and Rhodes in 1978, based on the work of Farrell (1957). DEA provides a new definition of efficiency, applicable to evaluation of the activities of not-for-profit entities participating in public programmes, measured using DEA. Numerous researchers have studied DEA, both theoretically and practically. The theoretical works have produced developments based on CCR (Charnes et al. 1978) and BCC (Banker et al. 1984), and propose very sophisticated models such as dynamic DEA, network DEA and stochastic DEA, comprising categorical variables - discretionary and non-discretionary, negative and undesirable variables, and many more. In practice, DEA has been applied in a wide range of applications such as banking, agriculture, transportation, health care, energy sectors, education and many other sectors.

There are several interesting reviews (both general and specific) related to our study. The group of more general reviews includes the first review of DEA, conducted one by Seiford and Thrall (1990), which examines its early-stage developments. Seiford (1996) provides a DEA bibliography covering the period 1978-1996, while Grosskopf (1996) provides a short, selective survey of statistical inferences and nonparametric efficiencies. Gattoufi et al. (2004) report a list of DEA related studies conducted over the period 1951-2001. Cooper et al. (2007) discuss past DEA models and measures, and potential developments. Emrouznejad et al. (2008) provide a bibliography of references related to DEA covering the first 30 years of DEA development. Cook and Seiford (2009) describe DEA developments since the late 1970s. Liu et al. (2013a, b) conduct two citations-based DEA literature analyses covering 1978 to 2010, and Lampe and Hilgers (2015) provide a comprehensive joint analysis of DEA and Stochastic Frontier Analysis (SFA) publications. The most recent reviews are Liu et al. (2016) and Liu et al. (2015). Liu and colleagues present a citations-based literature review of bootstrapping and two-stage analysis, undesirable factors,

cross-efficiency and ranking, network DEA, dynamic DEA and Slack Based Models (SBM) used in DEA, over the period 2000-2014.

The group of more specific reviews includes surveys of DEA applications to specific fields. Zhou et al. (2008) review the use of DEA in the fields of energy and the environment. Hollingsworth et al. (1999) examine work on the application of DEA to hospitals and the wider general health care context. Some works investigate the implications of frontier efficiency measurements (both parametric and non-parametric) in various fields. For instance, Hollingsworth (2003) presents the methods used in analyses and practical applications of measurement techniques (DEA and SFA). Oum et al. (1999) and Gonzalez and Tujillo (2009) review efficiency measurement studies in respectively rail transport and ports. Worthington (2004) provides a comprehensive review of the implications of frontier efficiency measurements applied to health care in 2004.

The DEA model has proven successful in banking and much of the theoretical work on DEA uses the banking industry as an example to illustrate the numerical or experimental results of new techniques.

Berger et al. (1993) reviews studies of efficiency in financial institutions and possible improvements. Berger and Humphrey (1997) review 130 studies on the application of frontier efficiency to financial institutions in 21 countries. Thanassoulis (1999) discusses application of DEA in the banking industry. Fethi and Pasiouras (2010) provide a survey of over 196 studies of operational research and artificial intelligence techniques used to evaluate banks' performance. The most recently published survey on the efficiency and performance of financial institutions is by Paradi and Zhu (2013), which reviews DEA applications in 80 bank branches. These specific surveys do not adopt quantitative methods, such as citations network analysis, to analyse a large sample of papers. Also, existing reviews refer to a narrow stratum of the financial services sector. We complement the citations network analyses with a qualitative investigation of the most

relevant papers identified. We highlight the different models and potential applications of DEA in three wide strata of the financial sector - banking, insurance and money market funds. Our analysis covers a long-time period (1985-2016) and provides an overview of the most recent applications and methodological advancements in DEA in financial services. Using data from ISI Web of Science (WoS) academic database of financial institutions, we contribute to research on DEA efficiency along several dimensions.

First, we examine a large set of financial institutions. Following Berger and Humphrey's (1997) survey on the efficiency of financial institutions, there have been numerous studies of financial institution efficiency, including analyses of insurance companies, money market fund providers and brokerage firms. However, the practicality of adopting of DEA to evaluate the efficiency of complex financial institutions warrants some further investigation necessary. Second, since Berger et al. (1993), most reviews focus only on the banking or only on the insurance industry. This makes a comprehensive survey of DEA applications in financial services timely and valuable. Third, Liu et al.'s (2013) review focuses on DEA applications and ranks DEA-application in the banking field. The banking, finance and insurance sectors constitute around 12.5% of all DEA application-embedded papers in their study, which is higher than for other fields. Thus, a review that focuses only on DEA application in the financial service sector should be useful.

To deal with the numerous works on DEA published since 1978, we adopt a network-based approach. We analyse the use of DEA in financial institutions by investigating the main networks of collaboration among researchers active in this sector and provide a snapshot of the main flows of ideas characterizing studies of DEA in financial institutions.

2. Data and methods

The study of citations to documents has a long tradition. Since the work of Garfield et al. (1964), the study of citations to scientific publications has received increasing attention from network

analysts, and the network analysis literature includes a growing number of contributions on identification of the so called main path, that is, the main flow of ideas underlying the field of analysis (Necmi Kemal Avkiran and Alpert 2015; Nerur et al. 2008; Whitley and Galliers 2007); technological developments and trajectories in various scientific fields (Barberá-Tomás et al. 2011; Bekkers and Martinelli 2012; Bhupatiraju et al. 2012; Breschi and Lissoni 2003; Epicoco 2013; Fontana et al. 2009; Martinelli 2012; Mina et al. 2007); and emerging knowledge trends within disciplines (Ding et al. 2013; Emrouznejad and Marra 2014; Fan et al. 2014; Lampe and Hilgers 2014; J. S. Liu et al. 2013; Rotolo et al. 2013). Network analysis assumes that, in a citations network (see Figure 1), document B cites document A, in other words, B relies on A to some extent. Thus, citations can be considered a proxy for knowledge flows. Note that the arrows in Figure 1 indicate the citing direction, present to past. The direction of knowledge flows from past to present if a paper published in the past affects subsequent papers. Lucio-Arias and Leydesdorff (2008) point out that: 'This reflects the diffusion of knowledge claims from an original document to documents published thereafter'. In a citations network the startpoint (initial unit) s is a vertex with zero in-degree, that is, no arc ends in that vertex, and the endpoint (target unit) t is a vertex with zero outdegree, that is no arc starts in that vertex. In Figure 1, vertices J, I, C are startpoints, while A is an endpoint. The traversal weight of an arc or a vertex is the proportion of all paths between the startpoint and the endpoint that contain this arc or vertex.

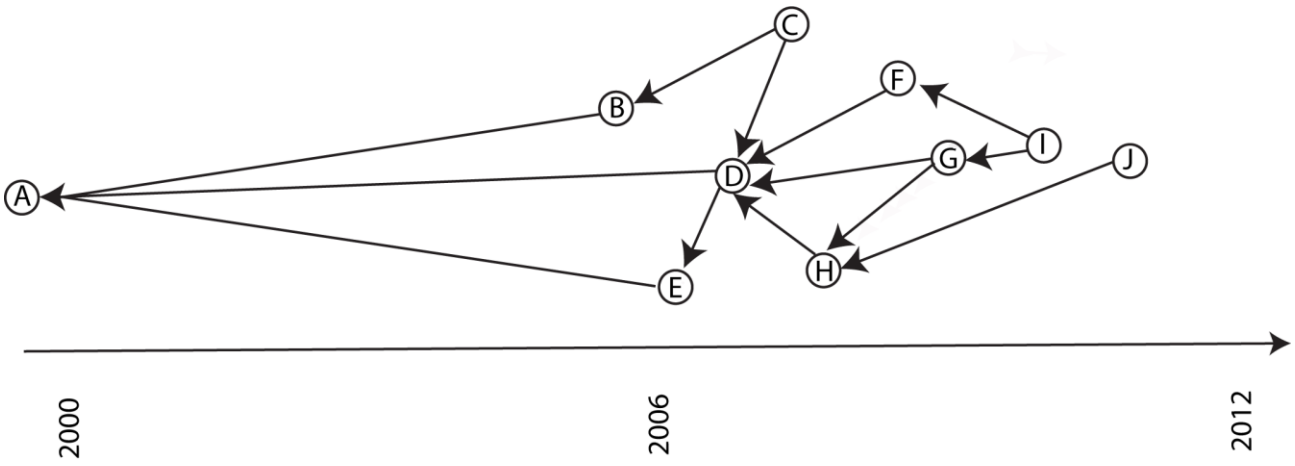

Figure 1. Example of a citations network

Our methodology draws on Hummon and Doreain (1989) and Batagelj (2003). The former proposed an innovation in citations analysis consisting of an approach in which the connective threads running through the network are preserved, and the focus is on the network links rather than the network nodes. Hummon and Doreain's approach to the analysis of connectivity is to focus on sequences of links and nodes or search paths. They propose two algorithms - Search Path Link Count (SPLC) and Search Path Node Pair (SPNP) - which represent a simple way of measuring the importance of a link. SPLC is a simple way of measuring the importance of a link and implies specification of the following concepts. SPLC consists of how many times one arc lies on all possible search paths between all startpoint nodes and endpoint nodes. It is based on counting the number of times a link is traversed by all possible search paths. In Figure 1 the citation arc DA obtains a SPLC value of 3. There are three possible search paths (J➔A; I➔A; C➔A). Arc 'DA' lies on these three.

SPNP accounts for all connected node pairs along the search paths, and assigns to each arc the product of the number of its upstream and downstream vertices, thus, an arc in the middle will receive a higher value. The logic underlying SPNP is that citation arcs responsible for connecting higher numbers of nodes contain the most significant knowledge flows in the citations network. In

Figure 1 the value of SPNP of arc 'DE' is the result of the product of 8 upstream vertices (D, B, C, H, F, G, I, J) to 2 downstream vertices (A, E), (8x2=16).

Batagelj's (2003) elaboration of the search path count (SPC) algorithm is considered the best development of Hummon and Doreain's algorithms originally applied to a small citations network which reconstructs the main path in the network of citations between scientific papers leading to the discovery of DNA. Batagelj (2003) also suggests applying the Critical Path Method (CPM) to the network. CPM comes from operational research and can be used to detect the main path in a citations network. CPM determines the s-t path with the maximal value of the sum of weights of the arcs in the path and provides a visual display of broader longitudinal connectivity than the SPC output (Kejžar et al. 2010). Thus, the CPM algorithm is expected to capture the foundations of the field of analysis under investigation, in our case DEA and financial services. Data are analysed using Pajek (Nooy et al. 2005) and HisCite (Garfield 2009) software[2].

The data are taken from the WoS database, which is a recognized, comprehensive, academic database covering over 10,000 high impact journals and over 120,000 proceedings of international conference, and is a valuable resource for scholars dealing with quantitative and citation-based studies. Data were retrieved using two groups of keywords combined using the search operators 'AND' and 'OR' within the WoS database. The first group was aimed at identifying the field of DEA. We searched for 'DEA', 'Data Envelopment Analysis', 'Malmquist index/indices', 'Total factor productivity', 'non-parametric efficiency' and 'nonparametric efficiency', and 'meta-frontier' and 'metafrontier'. We also searched for another group of terms, aimed at identifying papers dealing only with the area of financial service. We categorized the financial services sector according to four groups for which we used relevant keywords. The **banking industry** keywords

[2] Both software are freely available http://interest.science.thomsonreuters.com/forms/HistCite/ , http://mrvar.fdv.uni-lj.si/pajek/

are: 'banking', 'banks', 'financial institutions', 'micro-finance institutions', 'credit unions', 'financial holding companies (FHC)', 'banking holding companies (BHC)', 'loan and deposit companies', 'financial innovation systems', and 'mortgage loan companies'. Only 10% of the papers in this group were related to keywords other than bank and banking. The keywords for **money market funds** are 'investment funds', 'mutual fund', 'hedge funds', 'Real Estate Investment Trust (REITs)','private equity funds', and 'commodity index/indices'. The keywords for **insurance industry** are: 'insurance firms', 'pension funds', 'Takaful firm', 'compensation company' and 'property liability insurance'. We identified the main path within each thematic group using the CPM algorithm.

The advantage of a network based approach survey over the previous literature review approaches is that it identifies papers that play a vital role in the development of field using citations data. It presents how knowledge in a specific filed has been disseminated. Main path traces the development path of knowledge.

We manually retrieved some papers that were included in previous reviews, but were not identified by our search in WoS. We scrutinized each paper to ensure its relation to DEA and financial institutions, resulting in a final sample of 620 works published between 1985 and April 2016. Based on identification using keywords, banking group is the largest group with 514 papers. Insurance group includes 59 papers and money market funds has the smallest number of papers at 47. This study focuses only on papers that apply non-parametric frontier studies, specifically DEA, in financial services. We consider both methodology-oriented papers, which employ empirical examples in the financial services sector, and application-oriented papers, but exclude purely DEA methodology-oriented papers (for instance: Banker et al, 1984; Cooper et al., 2007). The yearly distribution of papers is depicted in Figure 2, which shows a peak in 2010 corresponding to 65 published papers. The lower value in 2016 is because data collection covered only the first four

months of 2016 when only 11 papers had been published. The highest number of papers was published in the *European Journal of Operational Research* (62) followed by *Journal of Banking and Finance* (*48*) and *Omega* (*34*) (Table 1). Tables 1 presents the top 20 ranked journals based on their Total Local Citation Score (TLCS), which is the number of times the journal's papers included in this collection were cited by other papers in the collection. We also show the Total Global Citation Score (TGCS), which refers to how many times the journal's papers were cited in the entire WoS database. In our case the two scores allow a better understanding of the importance of the journal within DEA and financial services, and also general interest in DEA and financial services per se. Within our sample, Sherman H.D. is the most important author, according to his TLCS (155), with 5 publications. He is followed by Paradi J.C. with TLCS equals 135, Gold F. with TLCS equals 103 and Lovell C.A.K. with TLCS equals 101.

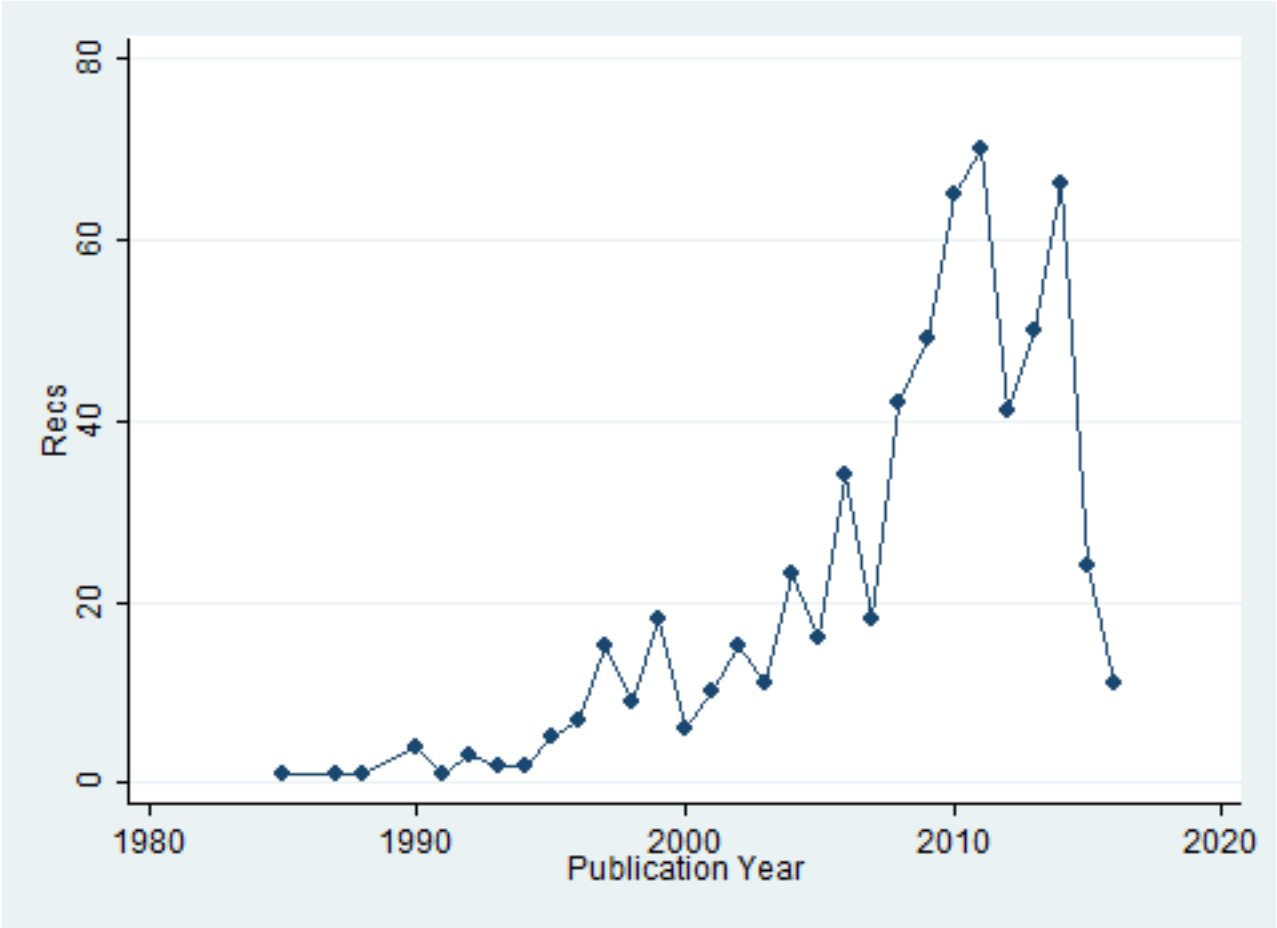

Figure 2. Distribution of papers per year

Table 1. Top 20 journals

	Journal	No of Papers	TLCS	TGCS
1	Journal of Banking & Finance	48	703	1483
2	European Journal of Operational Research	62	609	1643
3	Omega – International Journal of Management Science	34	206	616
4	Applied Economics	18	152	300
5	Journal of Operational Research Society	18	145	378
6	Interfaces	6	111	199
7	Journal of Productivity Analysis	21	87	352
8	Management Science	2	69	258
9	Journal of Money Credit and Banking	5	62	160
10	Expert Systems with Applications	28	58	220
11	China Economic Review	4	56	130
12	Economic Modelling	13	43	74
13	Engineering Costs and Production Economics	1	36	50
14	Journal of Econometrics	2	32	291
15	Geneva Papers on Risk and Insurance – Issues and Practice	8	31	36
16	Journal of Business Research	3	30	82
17	Service Industries Journal	13	29	93
18	Journal of Financial Services Research	2	28	76
19	Economics Letters	3	24	76
20	Annals of Operations Research	9	22	58

3. Geographical Distribution

In this section, in order to study the wide application of DEA in financial services, we explore the papers in each sub-sample based on four groups - single country studies, two-country studies, economic or geographical region studies, and global studies.

Table 2 illustrates the geographical distribution of banking group papers.

Table 2. Geographical distribution of banking group

Analysis Criteria								**Quantity**	**Perceptual**
Single Country Studies								**422**	**82%**
Country	**no.**	**Country**	**no.**	**Country**	**no.**	**Country**	**no.**		
Austria	1	Egypt	1	Malaysia	9	South Africa	2		
Australia	13	Finland	2	Mexico	3	Spain	18		
Bangladesh	5	France	2	Mongolia	1	Sweden	4		
Belgium	1	Germany	6	Nigeria	1	Taiwan	65		
Bosnia	2	Greece	15	Norway	4	Thailand	1		
Brazil	7	Hong Kong	3	Pakistan	3	Tunisia	1		
Bulgaria	1	India	16	Poland	1	Turkey	22		
Cameron	1	Indonesia	2	Portugal	8	UAE	2		
Canada	28	Iran	9	Romania	3	Uganda	1		
China	66	Ireland	1	Russia	1	UK	7		
Colombia	1	Italy	5	Saudi Arabia	1	Ukraine	1		
Croatia	2	Japan	9	Serbia	1	US	42		
Cyprus	3	Korea	4	Singapore	1	Vietnam	2		
Czech	4	Latvia	1	Slovak	4				
Two or Three countries Studies								**14**	**3%**
Countries	**no.**	**Countries**	**no.**						
China & Korea	2	Romania & Bulgaria	1						
China & Taiwan	2	Malaysia & Thailand	1						
Finland &UK	1	USA & UK	1						
German & Austria	1	USA & China	1						
India & Pakistan	3	USA & UK	1						
Economic or Geographical Regions Studies								**70**	**14%**
Region	**no.**	**Region**	**no.**						
CEE	8	Islamic countries	1						
European	32	Latin America	6						
Arab	3	South Africa	2						
Asia and East Asia	6	OECD	3						
GCC	4	EU & Canada	1						
MENA	1	EU & USA	1						
OIC	1								
Global Studies								**7**	**1%**
142 Countries	1	98 MIF	1						
18 countries	1	Six banks from							
Survey on 24	1	Fortune Global	1						

countries		500		
7 countries	1	Survey 196 studies	1	
72 countries	1			
Total*				**513**

*Not applicable for one study

CEE Central and Eastern European countries comprising Albania, Bulgaria, Croatia, Czech Republic, Hungary, Poland, Romania, the Slovak Republic, Slovenia, and the three Baltic States: Estonia, Latvia and Lithuania, **GCC** Golf Corporation Council Countries including Saudi Arabia, Kuwait, the United Arab Emirates, Qatar, Bahrain, and Oman, **MENA** Middle East and North Africa, **BRIC** Brazil, Russia, India and China, **OECD** Organisation for Economic Co-operation and Development, including 34 countries, which includes 21 of the 28 European Union members, **OIC** Organization of Islamic Conference countries

Table 2 shows that although 55 countries feature in various single-country studies, a disproportionately large number of studies is focused on just a few countries. For instance, the single-country studies show that the three most frequent countries (US, Taiwan and China) account for 41% of all the studies conducted, with the remaining 52 countries cumulatively accounting for just 59%. This might point indirectly to the fact that it is in these countries that DEA is most often employed in the banking sector.

Meanwhile, the study covering the largest number of countries is Hauner (2008), which studies the impact of credit to government on banking sector efficiency for 142 countries. We observe also that DEA has been applied extensively in the banking industry globally – evidenced by the fact that 142 individual countries are covered in these studies.

Table 3. Geographical distribution of Money market funds

Analysis Criteria				**Perceptual**
Single Country Studies				
Country			**32**	
Canada	**1**	**New Zealand**	**1**	**74%**
China	**8**	**Spain**	**2**	
Italy	**1**	**UK**	**2**	
Latin America	**1**	**US**	**16**	
Taiwan	**1**			
Region			**3**	**7%**
European			**3**	
Global Studies			**7**	**16%**
Total*			**43**	

* Not applicable for 4 studies

Table 3 shows the geographical distribution of money market group papers.

Table 3 also presents a skewed ratio, with 55% of the papers distributed between just China and the US for the single-country studies. A quarter of all papers, globally, is focussed on US money market funds, which is to be expected since it is an old and well-established market. However, there are only two papers on application of DEA in the UK, another well-developed, but apparently understudied market.

Table 4. Geographical distribution of Insurance industry

Analysis Criteria		Analysis Criteria		Perceptual
Single Country Studies		***Single Country Studies***		
Country		**49**		**84%**
Angola	1	Jordan	1	
Australia	1	Malaysia	1	
Brazil	2	Mozambique	1	
Canada	2	New Zealand	1	
China	8	Portugal	1	
Croatia	1	Serbia	1	
Czech	1	Spain	4	
Germany	3	Taiwan	6	
Greece	2	Thailand	1	
Iran	2	USA	9	
Two countries Studies			**3**	**5%**
Countries				
China & Taiwan Slovenia & Croatia Czech & Slovenia				
Economic or Geographical regions			**6**	**10%**
Region				
BRIC	2	Islamic	2	
European	1	Asia, Africa and Latin America	1	
Global Studies			**1**	**1%**
36 Countries	1		**1**	
Total			59	

Table 4 presents the geographical distribution of insurance group papers. In line with the trend observed in the Tables 2 and 3, again the US, Taiwan and China have the largest number of papers on application of DEA in the insurance industry. Note also that in this industry, DEA application has been studied in a multi-country context, for example, including the BRIC, Islamic and EU countries.

4. Main Path

In this section, we describe the main trajectories of DEA developments in financial services based on two individual main paths: banking group and money market fund group. The nodes are

papers and the arrows show the direction of the knowledge flows. Each of the papers in the figures is indicated by first author name and date of publication. For example, the paper by Sherman and Gold (1985) is indicated as 'Sherman1985'.

4.1 Banking main path

Figure 3 depicts the main path for the banking group, which includes 514 papers, 33 of which are located on the main path.

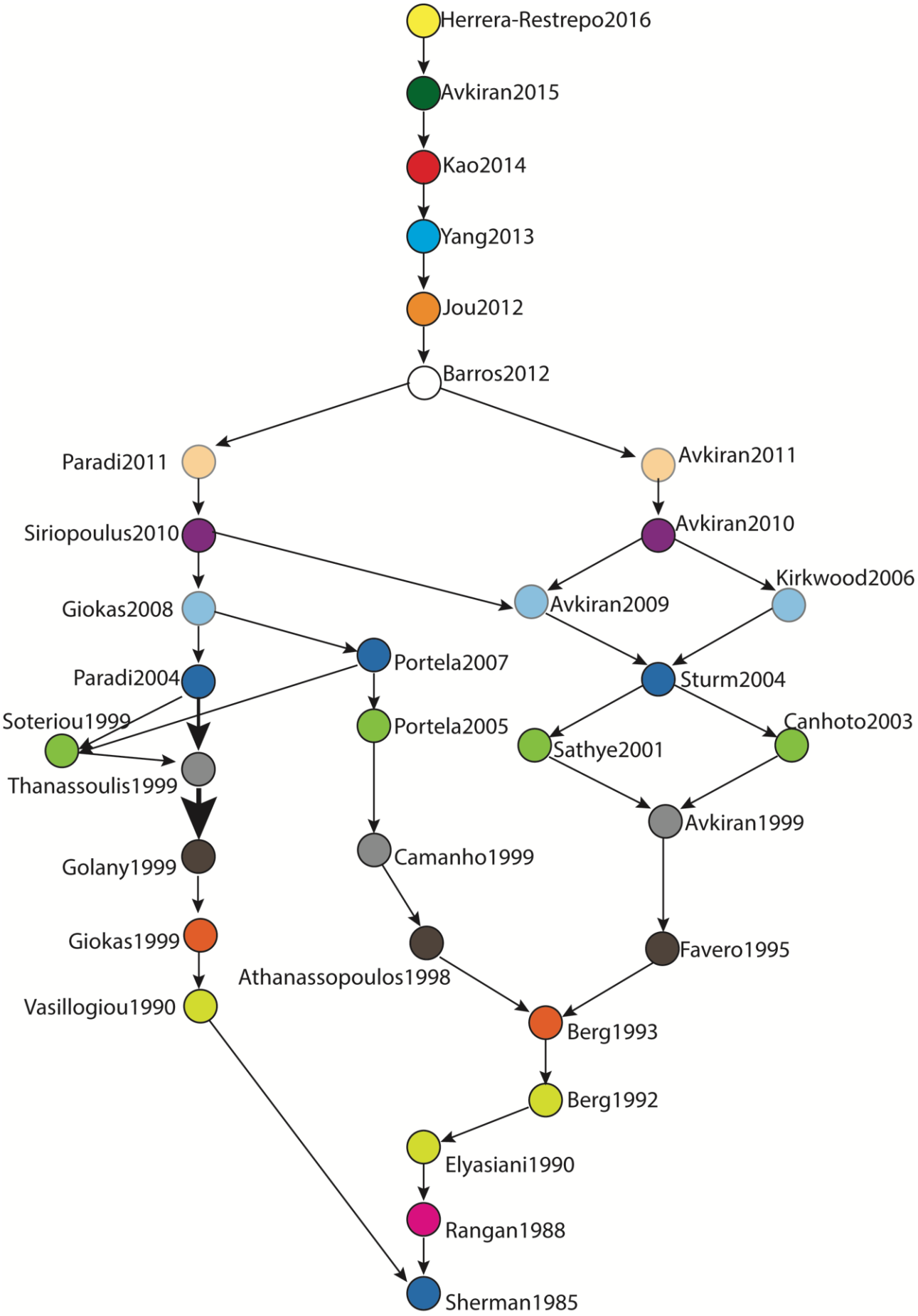

Figure 3. Banking main path

The first paper on the main path, which is the first published paper on the application of DEA in the banking sector is Sherman1985 Sherman and Gold (1985). It evaluates the operating efficiency of a set of 14 branches of a US savings bank. Two main streams originate from Sherman1985. While the right stream focuses mostly on DEA banking papers at country level, the left stream includes mainly DEA banking papers at bank branch level.

The left stream, Vassiloglou1990 (Vassiloglou and Giokas 1990), presents a systematic application of DEA to assess the relative efficiency of the branches of the Commercial Bank of Greece. Giokas1991 (Giokas 1991), compares the DEA efficiency of 17 branches of the Commercial Bank of Greece in 1988, based on the results of a log-linear model. The findings show that DEA takes account of the structure branch inputs compared to other estimation models. Golany1999 (Golany and Storbeck 1999) develops a number of innovative application tools, including budgeting and target setting models, by applying multi-period DEA to study the efficiency of the branches of a large US bank. The line between this paper and the following paper, Thanassoulis1999 (Thanassoulis 1999) is thicker, which shows a stronger impact on the development of the flow of ideas. Thanassoulis1999 conducts a branch level survey of efficiency in two large banks in Britain and Finland. Two nodes originate from Thanassoulis1999. The first node Paradi2004 (Paradi and Schaffnit 2004), which is the line with the stronger link, focuses on assessing the efficiency of the commercial branches of a large Canadian bank, by introducing the branch's non-discretionary environmental factors and producing Gap maps and target tables for each branch. The second node, Soteriou1999 (Soteriou and Zenios 1999) develops three DEA models - an operational efficiency model, a service quality efficiency model and a profitability efficiency model - to evaluate the performance of the branches of a commercial bank in Cyprus. Their results indicate superior insights when the operations combined with the quality of the services provided and the bank's profitability are analysed simultaneously rather than separately.

Giokas2008 (Giokas 2008) assesses the efficiency of the branches of a Greek bank from three different dimensions - management of the branch's economic performance, meeting demands for transactions from customers, and generating profits.

The left stream includes two papers. The first, Siriopoulos2010 (Siriopoulos and Tziogkidis 2010), studies the efficiency of 11 Greek banks employing a financial analysis and credit approach, over the period 1995-2003. The authors propose a Change Management Efficiency (CME) index to measure the efficiency of management through a process of change while presenting aggregate figures for the banks' branch development and performance. The second paper, Paradi2011 (Paradi et al. 2011), develops a two-stage DEA analysis approach applying a modified SBM model to aggregate the efficiency scores obtained from the first stage, and generates a composite performance index for each unit for the national branch network of a Canadian bank.

The next paper, where the left and right streams merge, which is Barros2012 (Barros et al. 2012), analyses the technical efficiency of Japanese banks in 2000-2007 using an innovative methodological model based on the Russell directional distance function which considers desirable and undesirable outputs.

The right stream, follows a paper by Rangan et al. (1988) (Rangan1988), which applies a non-parametric frontier approach to measure the technical efficiency of 215 US banks, while Elyasiani1990 (Elyasiani and Mehdian 1990) defines the rate of technological change as the rate of growth of total factor productivity, employing a non-parametric technique for a sample of 191 US banks in 1980-1985. The fourth paper on the right stream path, Berg1992 (Berg et al. 1992), studies productivity growth in banking based on application of a frontier production function within a DEA framework. Berg et al. generalizes the definition of the Malmquist index in the context of cross-section-time-series data. The right stream continues through Berg1993 (Sigbjørn Atle Berg et al. 1993), which exploits the Malmquist indices in Berger et al. (1992) to characterize the

productivity differences among banks in the Nordic countries, by studying their productivity differences relative to the respective national best practice frontier. Two streams originate from this node - a left-right stream and a right-right stream. The left-right stream begins with Berg1993 and is followed by Athanassopoulos1998 (Athanassopoulos 1998) and evaluates the efficiency of 580 branches of a commercial bank in the UK, distinguishing between market and cost efficiencies. In the next paper, Camanho1999 (Camanho et al. 1999) study the efficiency of Portuguese bank branches and the relationship between size and efficiency, by applying an efficiency-profitability matrix. Portela2005 (Portela and Thanassoulis 2005) applies a newly-developed method to 57 Portuguese bank branches to measure efficiency, and identify the sources of shortfalls in technical and allocative efficiency. Portela2007 (Portela and Thanassoulis 2007) evaluates the performance of the branches of a Portuguese bank over the period 2001-2002 by considering three different areas of performance; fostering the use of new transaction channels; increasing sales and the customer base; and generating profits. Their results suggest positive links between operational and profit efficiency and, also, between transactional and operational efficiency. Portela2007 merges the left-left stream with the right stream in Soteriou1999 and Giokas2008.

The right-right stream is followed by Favero1995 (Favero and Papi 1995), which derives measures of technical and scale efficiency for 174 Italian banks in 1991. From a methodological perspective, in order to allow for an explicit role of financial capital, Favero1995 modifies the traditional specifications of inputs. Avkiran1999 (Necmi Kemal Avkiran 1999) investigates the effect of a merger on the efficiency of Australian banks over the period 1986-1995. Two one-node branches originate from Favero1995 and merge in Sturm2004 (Sturm and Williams 2004). Avkiran1999 studies the technical efficiency of Portuguese banks over 1990-1995 and compares the relative efficiency of old banks versus new banks, and Sathye2001 (Sathye 2001) measures the X-efficiency of 29 Australian banks in 1990 and compares the efficiency of domestic and foreign banks. Sturm

and Williams (2004) analyses the efficiency and productivity growth of Australian banks during post-deregulation, and investigates the impact on bank performance of the entry of foreign banks into the country. The path continues through two single-node streams originating from Sturm2004, which join together in Avkiran2010 (Avkiran and Morita 2010). Kirkwood2006 (Kirkwood and Nahm 2006) assesses the cost efficiency of Australian banks over the period 1995-2002 and Avkiran2009 (Avkiran 2009) employs two existing DEA techniques at a sophisticated level; the first applies a slack-based DEA to measure the profit efficiency of United Arab Emirates (UAE) domestic commercial banks in 2005; the second applies a network slack-based DEA to simulated profit centre data, which rely on actual aggregate data for the UAE. Also, Avkiran2010 evaluates a firm compared to its peers from a stakeholder perspective (Avkiran and Morita 2010). The next paper in the right stream, Avkiran2011 (Avkiran 2011), examines the association between efficiency estimates and key financial ratios for Chinese commercial banks. It follows through Barros 2012 where the left stream joins the right stream.

The main path is followed by Juo2012 (Juo et al. 2012), which presents a non-oriented SBM to decompose the change in operating profits into a technical change effect and a profit efficiency effect. To illustrate their application of the approach, they examine a panel of 37 Taiwanese banks over 1994-2002. Yang2013 (Yang and Morita 2013) combines DEA with Nash Bargaining Game (NBG) theory and proposes a method to select an appropriate scheme to improve the efficiency of a bank based on multiple perspectives. The method is applied to a set of 65 Japanese banks.

Kao2014 (Kao and Liu 2014) use a relational network mode to illustrate the idea of multi-period efficiency measurements. After Kao2014, the main path diverges into two single-paper streams: these are the papers at the end of path, published more recently. Avkiran2015 (Avkiran 2015) illustrates dynamic network DEA (DN-DEA) in commercial banking, emphasizing testing robustness in the context of Chinese foreign banks versus domestic banks, between 2008-2010.

Herrera-Restrepo2016 (Herrera-Restrepo et al., 2016) proposes a multi-step procedure to identify bank branch managerial clusters and to study the operational efficiency of Canadian bank branches.

Thus, most papers in the left stream are branch level studies and the few more recent studies are at bank level. The first few papers in the right stream are bank level studies. Moving forward, in the left-right stream we observe branch level studies while right stream papers are bank level studies in different geographical regions.

Table 5 provides a better understanding of the main characteristics of each paper in the main route by analysing the studies on the main path, based on description of the study sample, select inputs and outputs, and the model and DEA extensions.

Table 5. Analysis of papers on the main path of banking group

Research	Evaluated DMUs				Input and Outputs		Model		
	Geographical region	Period of study	No. of DMUs	Study-level	Input	Output	Approach	Extension	Efficiency type
Sherman (1985)	US	1982	14	Branch	Labour, office space and supply costs	Four transaction types	PA	CCR	TE
Rangann et al. (1988)	US	1986	216	Bank	Labour, capital, purchased funds	Real estate loan, commercial and industrial loans, consumer loans, demand deposits, time and saving deposits	IA	N/A	TE
Elyasiani and Mehdian (1990)	US	1980-1985	191	Bank	Deposits, labour and capital	Real estate loans, commercial and industrial loans, other loans	IA	CCR	Rate of TE change
Vassiloglu and Giokas (1990)	Greece	1987	20	Branch	Labour, supplies, branch installation, computer terminals	4 transaction types	PA	CCR	TE
Giokas (1991)	Greece	1988	17	Branch	Labour, operating expenses, utilized branch spaces	3 transaction types	PA	CCR and BCC	TE
Berg et al. (1992)	Norway	1980-1988	152	Bank	Labour, materials	Short term loans, long term loans, deposit	VAA	CRS and VRS	Malmquist Index (MPI)
Berg et al. (1993)	Finland, Sweden, Norway	1990	779	Bank	Labour, capital	Loans, deposit, no. of branches	VAA	CRS and VRS	
Favero and Papi (1995)	Italy	1991	174	Bank	A) Labour, capital, current accounts, saving deposits, CDs, net funds, financial capital b) labour, capital, CDs, net funds, financial capital	a) Loans, investment, non-interest income b) loans, investment, non-interest income, current accounts, saving deposits,	IA, AA	CRS and VRS	TE and SE
Athanassopoulus (1998)	United Kingdom		580	Branch	a) Numbers of transactions, potential market, sales representatives, internal automatic facilities, branch outlets in the surrounding area b) direct labour costs, total technology facilities	a) Liabilities sales, loans and mortgages, insurance and securities, no. of cards b) no. of transactions, liability sales, loans and mortgages, insurance and securities, no. of cards	IA	CRS and VRS	ME and SE

Thanassoulis (1999)	United Kingdom and Finland	n/a	n/a	Branch	a) Production efficiency for UK branch: direct staff costs b) production efficiency for Finland branch: numbers of human tellers,computer terminals,branches, TMs c) market efficiency: numbers of facilities, umbers of sales persons, opening hours, markets, existing customers, transactions	a) Production efficiency for UK branch: Numbers of mortgage applications,insurance policies sold,new saving accounts, transactions, b) Production efficiency for Finland branch: Numbers of transactions by humans, cash withdrawals,loans processed, transactions by teller machine, c) market efficiency: mortgage policies, insurance sales, saving accounts	n/a	CRS	ME and PE
Golany and Storbeck (1999)	US	1992-1993	182	Branch	Labour, branch facilities	Market size, economic status of area, competitive activities	IA	CRS	OE
Avkiran (1999)	Australia	1986-1995	19	Bank	Staff numbers, deposits, interest expense and non-interest expense	Net loans, net interest income, and non-interest income	IA	CRS	XE
Camanho and Dyson (1999)	Portugal	1996	168	Branch	Number of employees in the branch, floor space of the branch, operational costs, number of external ATMs	Numbers of general service transactions performed by branch staff, transactions in external ATMs, types of accounts at the branch, and value of savings and loans	IA	CRS and VRS	TE and SE
Soteriou and Zenios (1999)	Cyprus	n/a	144	Branch	For all three types of efficiency; Resources (managerial personnel, clerical personnel, computer space), micro-environment (current accounts, saving accounts, foreign currency and commercial accounts, credit applications, commissions)	Operational efficiency: incident duration, waiting time, credit approval rate; service quality: reliability, responsiveness, assurance, tangibles, empathy; profitability efficiency: profit	IA, PA	CCR	OE, Service Quality Efficiency, PE
Sathye (2001)	Australia	1996	29	Bank	Labour, capital, loanable unds	Loans, demand deposits	IA	n/a	TE, AE, CE
Canhoto and Dermine (2003)	Portugal	1990-1995	20	Bank	Number of employees, physical capital	Loans, deposits, securities, interbank assets/liabilities, number of branches	IA	CRS and VRS	TE
Sturm and Williams (2004)	Australia	1988-2001			Model 1: inputs: employees, deposits, equity capital. outputs: Model 2: interest expenses, non-interest expenses.	Model 1: loans, off-balance sheet items. Model 2: net interest income, non-interest income.	IA	CRS and VRS	PTE, TE, SE

Paradi and Schaffnit (2004)	Canada	1995	90	Branch	Production: staff, equipment, premises usage, other non-interest expenses; strategic non-accrual loans	Production: deposits, loans, operating services, and account maintenance; strategic: deposits, loans and operating services	IA	CRS and VRS	TE, SC
Portela & Thanassoulis , 2005	Portugal	2001	57	Branch	No. of staff, supply costs	Value current accounts. Value other sources, value credit by bank, value credit associates	IA	VRS	PRE, TE
Kirkwood and Nahm (2006)	Australia	1995-2002	10	Bank	Service efficiency: Number of full-time equivalent employees interest-bearing assets, property, plant and equipment, non-interest income interest-bearing liabilities	Service Efficiency: interest bearing asset, non-interest income; profit efficiency: profit before tax and abnormal items	IA	CRS and VRS	TE, AE, Banking Service Efficiency
Portela and Thanassoulis (2007)	Portugal	2001-2002	57	Branch	Transactional efficiency: Number ATMs, Rent, No. clients not registered; operational efficiency: Number of staff, rent; profit efficiency: Number of staff, supply costs	Transactional efficiency: numbers of new registrations for internet use, transactions in CATs, deposits in ETM (ATMs+CATs); operational efficiency: Δ number of clients, Δ value current accounts, Δ value other resources, Δ value titles deposited, Δ value credit by bank, Δ value credit by associates, number transactions ; profit efficiency: value current accounts, value other resources, value credit over bank, value credit associates	IA	VRS	PRE, Transactional Efficiency, OE
Giokas (2008)	Greece	2002	44	Branch	Production efficiency and transaction efficiency: personnel costs, running and other operating costs intermediation efficiency: interest costs, non-interest costs	Production efficiency: value of loan portfolio, value of deposits, non-interest income; transaction efficiency: loan transactions, deposit transactions, remaining transactions; intermediation efficiency: interest income, non-interest income	IA	VRS	PE

Avkiran (2009)	UAE	2005	15	Bank	Interest expense, Non-interest expense a	Interest income, non-interest income	IA	VRS-SBM, NSBM	PRE
Siriopoulos and Tziogkidis (2010)	Greece	1995-2003	10	Bank	Financial analysis approach: unit vector as inputs ; credit approach: personnel expenses, provisions and operational expenses	Financial analysis approach: return on equity, financial independence ratio, gross operating margin, asset turnover ratio, service concentration index; credit approach: financial claims, operational income and earnings before taxes (EBT) divided by total assets	Financial credit approach, credit approach	CRS and VRS	TE, PE
Avkiran and Morita (2010)	China	2007	20	Bank	Shareholders perspective: Credit quality (equity/impaired loans (%));customers perspective: profitability (ROAE (%)), efficiency (income/cost (%)), value (dividend pay-out per share); management perspective: credit quality, value; employees perspective: efficiency, value	Shareholders perspective: soundness (capital adequacy ratio (%)), profitability, efficiency, value; customers perspective: profitability, efficiency, value; management perspective: soundness, profitability, efficiency; employees perspective: soundness, credit quality, profitability; regulators perspective: soundness, credit quality, profitability, efficiency, value;	n/a	VRS	Range-adjusted additive measure (RAM super-efficiency RAM (SRAM) score),
Paradi and Rouatt (2011)	Canada		816	Branch	Production approach: No of full time equivalent personnel; profitability approach: fund resources in $ values ;intermediation approach: expenses in $ values	Production approach: No. of transactions; profitability approach: earning assets in $ value ;intermediation approach: revenues in $ values	PA,PRA, IA	Modified VRS-SBM	PE, PE, International Efficiency

Avkiran (2011)	China	2007-2008	38	Bank	Core profitability model: Total interest expense, Total non-interest expenses; expanded profitability model: interest expense on customer deposits, other interest expense, personnel expenses, other operating expenses; financial ratio model: reciprocal of capital adequacy ratio, impaired loans/net interest income, impaired loans/total assets, impaired loans/equity, reciprocal of dividends per share, reciprocal of growth rate of assets	Core profitability model: gross interest and dividend income, total non-interest operating income , expanded profitability model: interest income on loans, other interest income, net fees and commissions, other operating income ; financial ratio model: growth rate of earnings per share, return on average equity, post-tax profit/average total assets, net interest income/average total assets, price to earnings ratio	IA	SBM, Super VRS-SBM	Core Profit Efficiency, Expanded Profit Efficiency, Financial Ratio Efficiency
Barros et al. (2012)	Japan	2002-2007	888	Bank	Number of employees, deposits, premises	Securities, loans, bad loans	IA	TE	WRDDM
Juo et al. (2012(tAIWAN dOLLAR))	Taiwan	1994-2002	37	Bank	Borrowed funds, labour, fixed assets; unit prices: average interest paid per TWD (Taiwan Dollar) of borrowed funds, ratio of labour cost to the number of staff, non-labour operational cost per TWD of fixed assets	Financial investments, loans; unit prices: average interest earned per TWD of investment, average interest earned per TWD of loans	IA	PRE change	Non-oriented SBM, BCC
Yang and Morita (2013)	Japan	2001-2006	65	Bank	Shareholder perspective: efficiency; customer perspective: credit quality, profitability, valuation; management perspective: efficiency, valuation; employee perspective: credit quality, valuation	Shareholder perspective: soundness, credit quality, profitability, valuation; customer perspective: soundness, profitability; management perspective: soundness, credit quality, profitability; employee perspective: soundness, profitability, efficiency	n/a	n/a	DEA+NBG
Kao and Liu (2014)	Taiwan	2009-2011	22	Bank	Labour, physical capital, purchased funds	Demand deposits, short-term loans, medium-and-long-term loans	IA	CRS	Rational network efficiency, connected network efficiency, aggregate efficiency

Avkiran (2015)	China	2008-2010	144	Bank	Interest expenses on customer deposits, other interest expenses, personnel expenses, other operating expense	Interest income on loans, other interest income, net fees and commissions, other operating income	IA	W-VRS non-oriented dynamic NSBM	TE
Herrera-Restrepo et al. (2016)	Canada	2004	966	Branch	Full-time equivalent service, sales, and management employees	Day-to-day, investment, borrowing, and over-the-counter transactions	PA	SBM	OE

PA: Production Approach, IA: Intermediation Approach, VAA: Value Added Approach, PRA: Profitability Approach

CRS: Constant Return to Scale; VRS: Variable Return to Scale; TE: Technical Efficiency; SE: Scale Efficiency; ME: Market Efficiency; CE: Cost-Efficiency; PE: Production Efficiency; PRE: Profit Efficiency; OE: Operational Efficiency AE: Allocative Efficiency; PTE: Pure Technical Efficiency; XE: X Efficiency; SBM: Slacks Based Measure; NSBM: Network Slacks Based Measure; WSBM: Weighted Slacks Based Measure; WRDDM: Weighted Russell directional distance model; NBG: Nash Bargaining Game

Table 5 shows out of 33 papers, on the main path 13 papers are branch-level studies and the others are bank-level studies. With the exception of Berg1993 and Thanassoulis1999, which study multi-country banking industry efficiency, the remaining papers focus on single-country data. Barros, Managi, and Matousek (2012) have studied the largest number of DMUs while Kirkwood2006 (Kirkwood & Nahm, 2006) and Siriopoulos2010 (Siriopoulos & Tziogkidis, 2010) study the smallest number of DMUs. Some authors have contributed more than one paper to the main path. Avkiran is the author of five papers on the path and Berg, Camanho and Paradi are first authors of two papers each, on the main path. 19 out of 33 papers on the main path apply an intermediation approach to the evaluation of evaluating DMUs, which shows the wide use of this approach compared to alternatives.

4.2 Money market fund main path

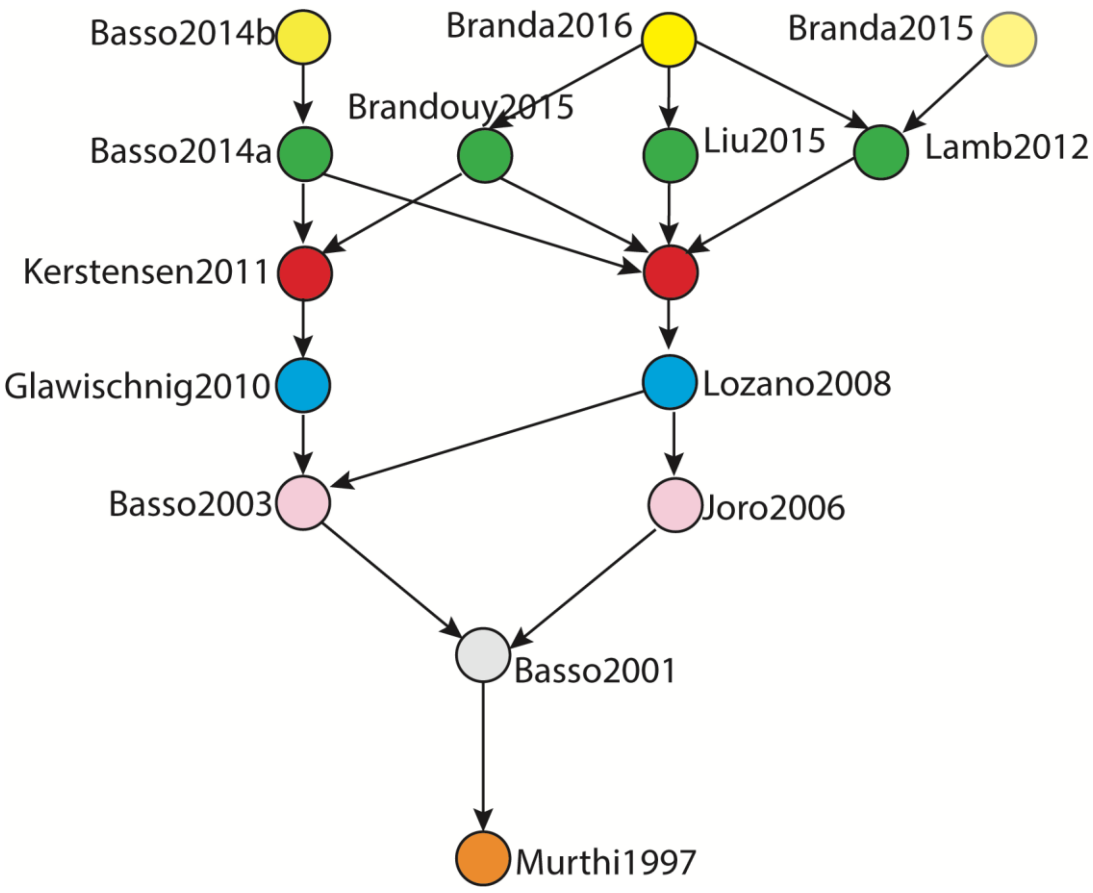

Figure 4. Money market funds main path

Figure 4 depicts the main path of the money market funds group. This path starts with a paper by Murthi1997 (Murthi et al. 1997), which introduces a new index to measure the performance of fund portfolios. There are two frequently used indices for assessing portfolio performance, Jensen's alpha (Jensen 1968) and the Sharpe index (Sharpe 1966). Murthi1997 proposes the DEA Portfolio Efficiency Index (DPEI) to address some additional issues. The authors compare the DPEI to traditional indices, applying them to 2,083 mutual funds in the third quarter of 1993. They also use 33 categories of funds, and evaluate DPEI to study the sources of variation in the means of DPEI across different categories, employing regression analysis.

Basso2001 (Basso and Funari 2001) is the next paper on the main path. There are four papers by Basso2001 on the main path, which is indicative of the significance of their work in the literature. Basso2001 defines new mutual fund performance indexes. Applying DEA allows these new indexes to take account of several inputs and outputs not considered by the traditional indexes. They apply their new model to 47 different classes of Italian mutual funds (stock funds, balanced funds and bonds funds) from January 1997 to end June 1999.

The main path then divides into two streams. We start with left stream, which begins with Basso2003 (Basso and Funari 2003). This paper presents a few models for measuring the performance of ethical mutual funds to consider their ethical components, expected returns, investment risk and subscription and redemption costs. The next two papers are Lozano2008 (Lozano & Gutiérrez, 2008), in the right-hand stream, and Glawischnig2010 (Glawischnig and Sommersguter-Reichmann 2010), in the left hand stream. Both provide critiques of DEA-based performance indexes to measure alternative investment fund performance. Although this new DEA-based performance index has the advantage that it considers multiple inputs (risk) and multiple outputs (returns), the author shows that this single real number performance index does

not include all the relevant information, overlooking, for instance, the amount of inefficiency in the factors, the importance of reference funds, and the endogenously derived weights. The authors show that a DEA-based index cannot replace financial performance indexes; however, these types of indexes provide new insights into the performance measurement of alternative investment funds. The paper by Kerstens2011 (Kerstens et al. 2011) is motivated by specification issues surrounding applications of non-parametric frontier models, for measuring the performance of mutual funds, and argues for the use of a shortage function and robust L-moment (Hosking, 1990), which are a novelty in frontier studies of mutual funds; 1,070 mutual funds taken from US and EU databases are employed to illustrate the assumptions underlying the modelling.

The stream continues through Basso2014a (Basso and Funari 2014a), where the right and left streams merge. Basso2014a proposes some new models to assess the performance of Socially Responsible Investment (SRI) funds. The authors investigate the presence of returns to scale in European SRI equity funds and compare the performance of SRI and non-SRI funds.

The right stream continues through Joro2006 (Joro and Na 2006), which develops a DEA framework for portfolio performance assessment, based on mean–variance–skewness. It provides an empirical illustration based on 58 mutual funds. Lozano2008 (Lozano and Gutiérrez 2008) introduce six DEA-like linear programming models to measure the relative efficiency of mutual funds consistent with second-order stochastic dominance. Two of the proposed models are mean-safety models while the remaining four are mean-risk types. These models are applied to 18 Spanish mutual funds over 2002-2005. The next paper in the right stream is Lamb2012a (Lamb and Tee 2012a), which introduces a stochastic DEA model by applying the bootstrap method to develop techniques for ranking funds and deriving confidence intervals. The authors demonstrate use of the bootstrap model to deal with the issues of substantial bias in investment fund performance, correlation in funds returns and accuracy of DEA estimates. They identify the need

for a DEA model based on a risk-returns ratio to gauge the performance of investment funds. They discuss how to handle scope for diversification and the relationship between diversification, coherent risk measures and stochastic dominance.

From Lamb2012a, the right stream splits into three short streams. The far right stream, Lamb2012, (Lamb and Tee 2012b) shows that efficiency estimates of investment fund performance using DEA models, typically show substantial bias, which is greater for high-risk, high-returns funds compared to low-risk, low-returns funds. Lamb and Tee develop a stochastic DEA model to deal with consistency, bias and correlation in funds' returns, by applying the bootstrap method. A sample of 60 monthly returns from 30 hedge funds during the period 2000–2004, is used to illustrate the proposed model. The next paper, Branda2015 (Branda 2015), proposes a new diversification-consistent DEA model which uses several risk measures as inputs and return measures as outputs, with both positive and negative values. They identify various models with different levels of Pareto–Koopmans efficient investment opportunities. They experiment using 48 representative industry portfolios from US stock markets. The paper positioned in the middle, Liu2015 (Liu et al. 2015), investigates the theoretical foundations of DEA models for portfolios, from the perspective of the sampling portfolio. They conduct comprehensive simulations and show that, with adequate data sets, the classic DEA model can be an effective tool to compute the portfolio efficiency in their performance assessments. This study confirms the effectiveness and practicality of the DEA method for assessing portfolio efficiency. The far left stream includes Brandouy2015 (Brandouy et al. 2015), which conducts a three part analysis to compare recent convex and non-convex frontier mutual fund rating models to traditional models. The authors conclude that frontier-based mutual fund ratings allow the design of investment policies which give better performance and which are more coherent and consistent compared to traditional financial performance measures.

These three short streams merge in Branda2016 (Branda 2016), which introduces a new diversification–consistent DEA model based on directional distance measure, and proposes reformulations under distributional assumptions, which allow efficient problem solving using second-order cone and mixed-integer linear programming. By considering inputs as value at risk on several levels, this diversification allows for risk-shaping based on multi-objective optimization and Pareto–Koopmans efficiency. The proposed model is an appropriate normal and finite discrete distribution of returns from a feasibility, optimal solutions and reformulations perspectives.

Table 6 summarizes the 15 papers on the main path in the money market group. Table 3 presents the geographical distribution of the money market papers. Four out of ten papers on the main path are by Basso and Funari (2003; 2001, 2014a, 2014b). Most of the papers on the money market main path apply DEA to propose a new index to measure the performance of money market funds especially mutual funds.

Table 6. Analysis of papers on the main path of money market fund group

Research	Evaluated DMUs				Input and Outputs		Model	
	Geographical Region	Period of study	No. of DMUs	Type of Money market	Input	Output	Orientation	Proposed model
Murthi et al. (1997)	US	3rd quarter 1993	2083	Mutual Funds	Expense ratio, Load, Turnover, Standard deviation	Return	Output-orientation	DEA portfolio efficiency index (DPEI) (multiple input-single output)
Basso and Funari (2001)	Italy	January 1997 to June 1999	47	Mutual Funds	Square root of the half-variance and the β-coefficient	Expected return, stochastic dominance	Input-orientation	DEA indexes (IDEA_1 and IDEA_2) reflecting the investors' preference structure and the time occurrence of the returns (multiple input-multiple output)
Basso and Funari (2003)	N/A	N/A	50	Simulated Mutual Funds	3 brackets of subscription costs, 3 brackets of redemption costs, 2 risk measures	2 outputs considered: expected return and an ethical indicator	Input and output orientation	DEA model considering the ethical aims as a second objective besides the investment return
Joro and Na (2006)	US	January 1995 to April 2000	54	Mutual Funds	Variance	Return, skewness	Input-orientation	Portfolio performance measure based on mean–variance–skewness framework
Lozano and Gutuerrez (2008)	Spain	January 2002 to December 2005	108	Mutual Funds	Return–risk models: return; return–safety model: constant*	Return–risk models: risk; return–safety model: return and safety	N/A	Six distinct DEA-like linear programming models; (4 return–risk DEA models plus 2 return–safety DEA)

Glawischni (2010)	N/A	N/A	167	Managed Future Fund	Investment risk measured in terms of standard deviation, lower partial moments (LPMs 0–4).	Compounded return to upper partial moments (UPMs 1–4) and maximum drawdown periods (MDP)	Input and Output orientation	DEA-based performance assessment models been investigated to see whether can meet all the desirable properties usually attributed to DEA-based evaluation
Kerstens (2011)	US and EU	January 2, 2004 to February 28, 2009	1068	Mutual Funds	Risk	Return	N/A	Discussing (i) the nature of returns to scale, (ii) the inclusion of higher moments and cost components, and (iii) imposing convexity or not for DEA in context of mutual funds models
Lamb and Tee (2012a)	Global	2000 and 2004	30	Mutual Funds	Nonnegative Risk measures	Return measures	Input-orientation	An iterative approximation to deal with negative risks and diversification
Lamb and Tee (2012b)	US	2000–2004.	30	Hedge funds	Max ($CVaR_{0.2}$, 0) and max (SD,0)	Mean return, max (-$CVaR_{.1}$, 0).	Input-orientation	Stochastic DEA models using bootstrap
Basso and Funari (2014a)	EU	June 2006–June 2009	558	Mutual funds, SRI funds, non-SRI funds	Coefficient as a risk measure of the investment in fund, Initial payout invested in fund	Final value for fund, ethical measure for fund	Output orientation	Constant and variable returns to scale DEA models DEA-CE efficiency and DEA-VE efficiency
Liu et al. (2015)	China	January 2008 to January 2013	5	Selected industry portfolios	Risk generated with risk function	Return generated from risk function	Input and Output orientation based	DEA models under the mean-variance

					and generated random weights for each portfolio model	and generated random weights for each portfolio model	on portfolio model	framework
Brandouy (2015)	EU	October 2005 to October 2011	814	Open-end mutual	Risk as well as several transactio n costs	Return		Convex and non-convex frontier-based with simple back-testing analysis
Basso and Funari (2014b)	EU	June 2006 to June 2009	190	SRI Mutual Funds	DEA-KC and DEA-KCE, DEA-KCE models: constant initial capital, standard deviation of the returns	DEA-KC model: final value; DEA-KCE and DEA-KCE: final value, ethical measure	Output orientatio n	DEA models; DEA-KC and DEA-KCE and DEA-KCE model; focusing on the main determinants of investments in SRI
Branda (2015)	US	January 2002 to Decemb er 2011	48	Selected industry portfolios	Coherent risk	Coherent return	N/A	Diversificatio n-consistent (DC) DEA
Branda (2016)	US	July 2004 June 2014	48	Selected industry portfolios	Value at risk on several levels	Return		Diversificatio n–consistent (DC) DEA based on directional distance

The various papers on the money market funds main path focus only on mutual funds. Basso and Funari make the biggest contribution to the papers on the main path (4 out of 10 papers). The largest number of observations (2,083) is for the paper by Murthi et al. (1997), which studies the DPEI of US mutual fund for one quarter of 1993.

Table 6 shows that the most recent studies develop novel indices using DEA to measure the efficiency of mutual funds.

4.3 Insurance main path

Figure 5 depicts the main route for insurance papers. There is a main path ending in two one-node streams, and consists of nine papers. The first three articles on the insurance path have the same first author. The first paper, Cummins2004 (Cummins et al. 2004), tests hypotheses on the effects of organizational structures on the efficiency of Spanish stock and mutual insurers, over the period 1989-1997, employing input-oriented distance functions. The second paper, Cummins2006 (Cummins and Rubio-Misas 2006), investigates the impact of deregulation and consolidation on Spanish insurance industry costs, technical and allocative efficiency over 1989-1998, and changes to TFP. The third paper, Cummins2008 (Cummins and Xie 2008), studies the effect of mergers and acquisitions on the efficiency of the US property-liability[3] insurance industry, during the period 1994-2003, employing a value-added approach to specify inputs and outputs.

Eling2010 (Eling and Luhnen 2010) analyses the efficiency of a broad international dataset consisting of 6,462 insurance companies in 36 countries, over 2002-2006. To measure technical and cost efficiency, the authors apply both DEA and SFA. Cummins et al. 2010 (Cummins2010) adopt two-stage DEA to investigate the efficiency of US insurance companies during the period 1993-2006, and examine the efficiency levels of insurance companies offering both life-health and property-liability services, and those offering these services separately.

After Xie2011 (Xie et al. 2011), the main path divides into two streams. Xie et al. provide technical and cost efficiencies for 37 US life insurance firms experiencing demutualization and examine whether converting firms experience post-demutualization efficiency improvements. The right stream, which originates from Xie2011, includes Barros2014 (Barros and Wanke 2014), which

[3] Property-liability insurance pricing was proposed in 1926 to integrate underwriting and investment performance. A description of the development of property-liability insurance pricing models can be found in Cooper (1974) and D'Arcy and Doherty (1988).

estimates the efficiency of Mozambique insurance companies by applying bootstrapping to classical BCC and CCR. In order to identify the major input and output slacks and predict them against the contextual variables, principal component analysis and neural network analysis are applied. In the left-hand stream, Barros2014 (Barros et al. 2014) studies the performance of Angolan insurance companies between 2003 and 2012. The right and left streams merge in Wanke2016 (Wanke & Barros 2016). Wanke and Barros employ a two-stage DEA to investigate the role of heterogeneity in the insurance sector. In the first stage they use DEA meta-frontier and, in the second stage, they use a number of data mining techniques. They apply the model to a balanced panel data set of Brazilian insurance companies and show that there is a heterogeneous impact on the efficiency levels of geographical regions and insurance types of insurance companies.

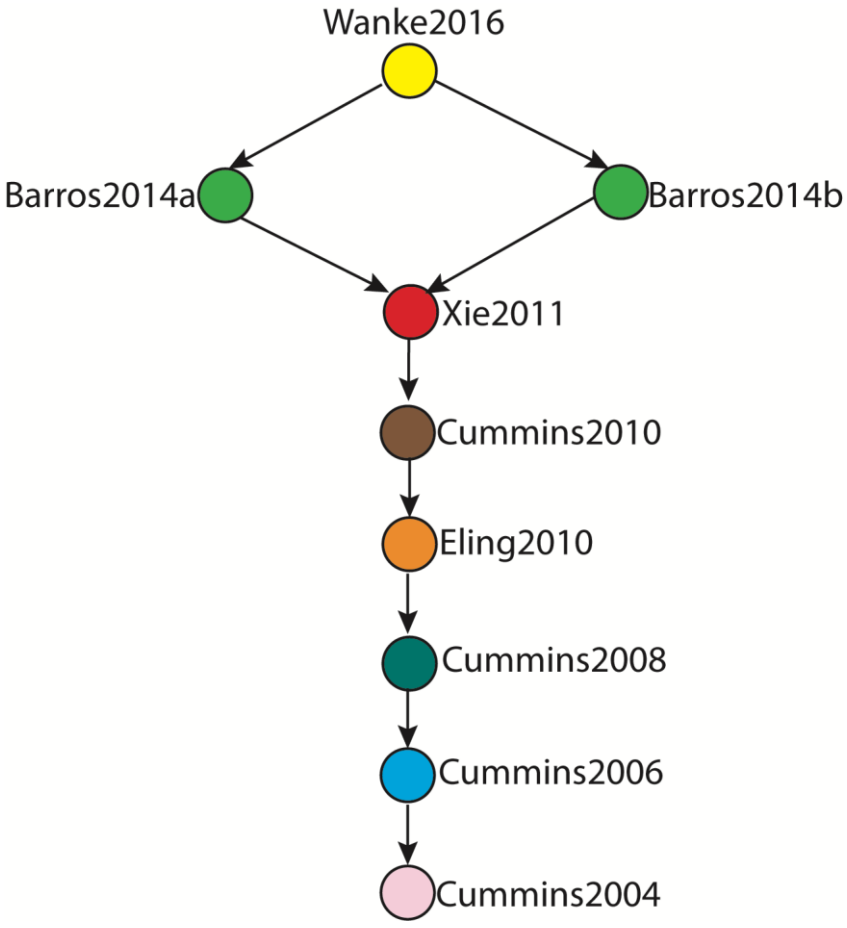

Figure 5. Insurance main path

Table 7. Analysis of papers on the main path of insurance group

Research	Evaluated DMUs				Input and Outputs			
	Geographical region	**Period of study**	**Quantity**	**Type of Insurer**	**Input**	**Output**	**Environmental variable**	**Efficiency type**
Cummins et al. (2004)	Spain	**1989–1997**	3121	Stock and mutual insurers	Labour, business, financial debt capital, equity capital	Life and non-life insurance losses incurred	Organizational structure	Technical, cost, and revenue efficiency
Cummins and Rubio (2006)	Spain	**1989-1998**	3831	Insurers	Labour, business services, debt capital, equity capital	Life and non-life insurance losses incurred, reinsurance reserves, reserves for primary insurance contracts, invested assets	Deregulation, consolidation	Cost, technical, allocative efficiency
Cummins and Xie (2008)	**US**	**1993-2003**	Acquiring firms: 150; non-acquiring firms 6255 target firms: 241; non-target firms: 8694	property-liability insurer	Administrative labour, agent labour, materials, business services, financial equity capital	Personal lines short and long-tail coverages, commercial lines short and long tail coverages,	Mergers & acquisitions	Cost, technical, allocative, pure technical, scale, revenue efficiency-Malmquist indexes
Eling and Lugnen (2010)	36 countries	**2002-2006**	26,505	Life and non-life insurance insurer	Labour and business, debt capital, equity capital; service,	Non-life claims + additions, life benefits + additions to reserves, investments to reserves,	N/A	Technical, cost efficiency
Cummins et al. (2010)	US	**1993–2006**	Life health: 3160; Popper-liability: 8635	life-health and property-liability	Home office labour, agent labour, business services, equity capital	Individual life, individual annuities, group life, group annuities, accident and health, intermediation	N/A	Technical, pure technical, cost, scale, revenue, allocative efficiency, profit inefficiency

Xie et al. (2011)	US	**1993-2003**		Life insurer	Administrative labour, agent labour, materials, business services, financial equity capital.	Individual life insurance, Individual annuities, group life insurance, group annuities and accident and health insurance, one intermediary output (invested assets) is defined for financial intermediation services provided by insurance companies.	Demutualization, control	Cost, technical efficiency
Barros and Wanke (2014)	Mozambique	**2002–2011**	N/A	N/A	Operating costs, number of employees, wages, capital	Claims paid, profits paid, premiums earned, ceded reinsurance	N/A	Technical, bootstrapped efficiency
Barros et al. (2014)	Angola	**2003-2012**		Life and non-life Insurer	Operating costs, number of employees, wages, capital	Claims paid, profits paid premiums earned, ceded reinsurance	N/A	Technical, bootstrapped efficiency
Wanke and Barros (2016)	Brazil	1995–2013	Wanke and Barros (2016)	Brazil	1995–2013	Wanke and Barros (2016)	Brazil	1995–2013

Table 7 presents the geographical distribution of insurance group papers. US, Taiwan and China have the largest number of papers on the application of DEA in the insurance industry. DEA has been applied in several multi-country studies of the BRIC, Islamic and EU countries.

Most papers on the insurance main path focus on the efficiency of life and non-life, property-liability insurers. The largest data sample is in the study by Eling and Lugnen (2010), which examines the efficiency of life and non-life insurance companies in over 36 countries. Three out of eight papers on the path focus on US data, which shows the importance of these studies in the literature. Comparing Tables (7) and (5) shows that very few sophisticated DEA techniques have been applied to measure the efficiency of insurance companies.

Conclusions

DEA research in financial services studies has increased in recent years. The resulting large DEA literature makes it difficult to conduct a general review without resorting to quantitative methodologies.

The availability of data in this field from databases, such as Bank-Scope, especially in the banking domain, has resulted in these data being used to experiment with the newly developed DEA models. In this paper, we surveyed DEA applications in the context of financial services using a quantitative and citations network approach. We identified significant paths, important papers, and innovative methodologies related to the application of DEA in financial services. We identified three main areas of application within the financial services sector - the banking industry, the insurance industry and money market funds. We considered 596 articles from the year 1985 onwards, which, in our view, provides a thorough mapping of the field.

We highlighted the main flow of ideas characterizing analyses of efficiency using DEA. Our examination of individual main routes suggests that there are no obvious methodological preferences for any of the corresponding three areas. Recent innovations in DEA methodologies (network models, slacks based models, directional distance models and Nash bargaining game) clearly dominate the ends of the routes on the main paths. Geographical analysis of the papers in

our sample showed that banking systems are the most frequently studied systems - especially for the US, China, Taiwan, Latin-America, Japan and the Arab countries.

This study has some limitations. The sample was taken from the ISI WoS, which is recognized as the largest citation-based academic database. However, some works dealing with DEA and financial services may not be included in the WoS, which means this study is less comprehensive than ideal.

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