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A survey on bank branch efficiency and performance research with data envelopment analysis

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ABSTRACT

The banking industry has been the object of DEA analyses by a significant number of researchers and probably is the most heavily studied of all business sectors. Various DEA models have been applied in performance assessing problems, and the banks' complex production processes have further motivated the extension and improvement of DEA techniques. This paper surveys 80 published DEA applications in 24 countries/areas that specifically focus on bank branches. Key issues related to the design of DEA models in these studies are discussed. Much advice is included on how to design future experiments and studies in this domain. A number of areas where further research could be fruitful are suggested.

1. Introduction

As the principal sources of financial intermediation and channels of making payments, banks play a vital role in a country's economic development and growth. In addition to their large economic significance, the existence of an increasingly competitive market highlights the importance of evaluating the banks' performance in order to continuously improve their functions and monitor their financial condition. There are many uses for performance analyses by bank management concerned with the identification of the sources of operating inefficiency, gaps in effective resource allocation, the impacts of ongoing regulation changes on bank operations, and their ability to realign their businesses with the current and most profitable business trends, etc.

Among the wide spectrum of modeling techniques in the banking sector Data Envelopment Analysis (DEA) is one of the most successfully used operational research technique in assessing bank performance [1]. Due to its powerful optimizing ability, DEA allows management to objectively identify the best practitioners and the areas in need of improvement within the bank's complex operating situations. Although a considerable number of papers have been published on the banking industry using DEA since the technology was introduced, they mainly focused on studies at the institutional level. For example, we found 275 DEA applications in the banking sector between 1985 and 2011, among them 195 studies examined banking institutions as a whole, but only 80 on the branch level. There are three survey papers that reviewed DEA applications in the banking industry. However, all of them focused on the studies that analyzed efficiency at the bank level. Berger and Humphrey [2] were the first to review five major efficiency analysis techniques including DEA that were typically used to examine the efficiency of financial institutions in order to make some useful comparisons between their average efficiency levels. Out of the total of 130 studies reviewed by them, there were 57 DEA based papers, 42 focusing on the bank level and 15 on the branch level. Berger [3] reviewed over 100 applications of frontier techniques that compared bank efficiencies across nations. Fethi and Pasiouras [1] reviewed 196 studies employing operational research and artificial intelligence techniques in the assessment of bank performance. Among the 196 studies, 151 of them used DEA-like techniques to measure bank efficiency and productivity growth, and only 30 studies focused on the branch level.

Because the availability of data and the measures that matter to a bank, as an entity, or to a branch, as a unit, are very different, different approaches must be taken when studying banks as the decision making units (DMUs) as opposed to the cases where the bank branches are the DMUs. Furthermore, the purposes of the studies at the bank and branch level are also different. Based on our survey of 195 published studies at the bank level, the main application issues are

1) Efficiency changes over time due to banking liberalization and deregulation, market structure and economic environmental changes.
2) Effects of ownership and bank types.
3) Bank performance benchmark and improvement.
4) International comparison.

While the diversity of the business objectives of DEA applications at the branch level are enormous, most of them focused on

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evaluating the branch's specific operating aspects with a purpose of eliminating deficiency that can be controlled by branch managers, such as branch labor use efficiency, profitability, intermediation efficiency, cost efficiency, and investigating the determinants of efficiency, such as the business environment, branch size, technical innovations, etc.

Bank branch performance measurement is a very difficult task. Branches come in a variety of sizes, offering different services to different customers while operating in different economic regions. A relevant and trustworthy bank branch performance evaluation should be able to: (1) capture the essential aspects of the bank's internal operating processes; (2) lead to a better understanding of such processes in terms of what is achieved and how it is achieved; (3) provide management improvement guidelines by identify the best practices and the worst practices; and (4) allow a meaningful investigation of various hypotheses concerning the sources of inefficiency.

From many aspects, such analyses at the branch level are more desirable and more important than at the banking institutions' level. First, information on branch performance may help improve our understanding of the underpinnings of efficiency at the bank level and help resolve some measurement problems in the standard bank-level analysis [2]. Second, a bank's branch network represents typically the largest source of operational expenses for a bank. From a managerial point of view, cost management is more efficiently controlled at the branch level; hence the results from the analyses affecting the bottom line are close at hand. Furthermore, according to the information from the U.S. Federal Deposit Insurance Corporation (FDIC), the number of commercial banks in the U.S. had been declining since 1985, dropping by almost 52% in the period between 1985 and 2009. However, at the same time the number of bank branches had been steadily increasing by more than 90%, as shown in Fig. 1. Third, although the rapid technical evolution has led to new channels through which financial products and services can be delivered, such as automated teller machines, online banking, mobile banking, etc., it is through a branch that customers do a large percentage of their more value added banking. A Canadian study found that 61% of bank customers still visited their bank branches and on average made four trips per month (NFO CFgroup Poll, "Tellers still popular, study finds", The Toronto, Canada Globe and Mail newspaper, January 23, pp. B5, 2003). The research conducted by The Boston Consulting Group found that the financial crisis of 2008 had deepened the need among consumers and small businesses for reliability, reassuring face-to-face contact, and would result in a more important role for the local bank branch in the post crisis era ("Building a high-powered branch network in retail banking", The Boston Consulting Group, March 10, 2010). Therefore, the ability to

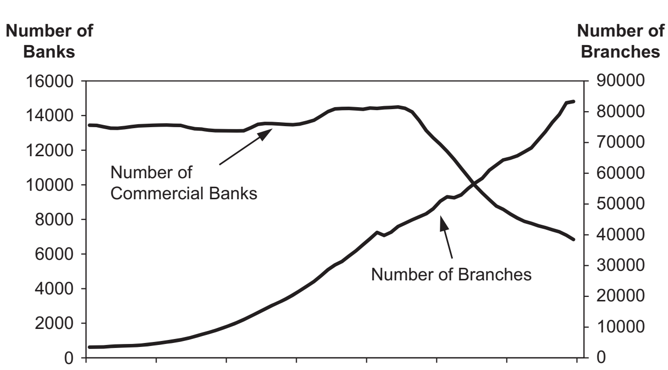

Fig. 1. Trends of the number of banks and branches in U.S.
(Data source: U.S. Federal Deposit Insurance Corporation, Historical Statistics on Banking).

continuously improve branch performance is crucial to help a bank win in an extremely competitive financial services marketplace and well-executed branch strategies, based on sound analyses, will, almost for certain, improve a bank's overall operating results.

With a growing number of studies using DEA in bank branch analysis, a survey of this field would be useful and timely. Since the first published paper about DEA application in a U.S. bank branch setting by Sherman and Gold [4], our survey identifies 80 DEA applications at the bank branch level. Section 2 discusses several most common performance measurement approaches that have been applied in the banking industry at the branch level. In Section 3, we summarize some interesting findings observed from the 80 studies examined, such as the distributions of the studied nations, the sizes of data sets used, and the timing of the publication of results. Section 4 reviews and segments studies according to their main research purposes. In Section 5, some considerations about model building are discussed with references to past work that could be helpful for researchers and practitioners when applying DEA to study bank branch issues. In Section 6, the areas needing further research are discussed and in Section 7 we draw our conclusions.

2. Performance measurement approaches applied to bank branches

Due to the rapidly increasing complexity of today's business environment, there is no universal agreement on the specification of bank branch performance and the challenge still remains in selecting the most suitable methodology for this important problem. At least four different approaches are commonly employed: ratio analysis, regression analysis, frontier efficiency analysis, and other artificial intelligence techniques, such as neural networks, analytic hierarchy processes and balanced scorecards, just to mention a few.

2.1. Ratio analysis

Historically, ratio analysis has been the standard technique used by regulators, industry analysts and management to examine performance at all levels. Ratios measure the relationship between two variables chosen to provide insights into different aspects of the branch's multifaceted operations, such as profitability, capital adequacy, asset quality, risk management, and many others. Any number of ratios can be designed depending on the objective of the analysis, the traditional financial ratios for estimating bank branch performance are return on total assets; return on investment; loans per employee; deposits per employee; cost to income and many others [5].

Although the traditional ratio measures are attractive to analysts due to their simplicity and ease of understanding, there have been many methodological problems and limitations that must be considered [5–8]. Its main weakness is that each of the ratios examines only a part of the unit's activities, which fails to reflect a bank branch's multidimensional nature and, hence, fails to yield enough performance information. Moreover, there seems to be an unlimited number of ratios that can be created from financial statement data and the results can be contradictory and confusing, and thus ineffective for the assessment of a branch's overall performance. Ratios, by their nature, are constant returns to scale and that is also clearly a problem when looking at a variety of branches where this does not apply. Furthermore, although ratios do provide certain useful information on the performance of a unit on specific aspects they are not suitable for setting improvement targets for inefficient units. Perhaps more importantly, from a human perspective, the branch managers find it easy to push back because they can safely claim that ratios are not adequate to help with the complexities they face each day and that ratios are unfair and inequitable.

Thanassoulis et al. [9] compared DEA and ratio analysis as alternative tools for assessing the performance of District Health Authorities in England. The comparison focused on how well the two methods agreed on the performance of a unit relative to that of other units and on the estimates of performance improvement targets. They found that the two methods could disagree substantially on the relative performance of individual units, which was mainly due to the fact that DEA took simultaneous account of all resources and outputs in assessing performance while ratio analysis related only one resource to one output at a time.

2.2. Regression analysis

Regression analysis is another common methodology used in previous studies of the bank sector based on input–output analyses, such as Olsen and Lord [10], Murphy and Orgler [11], Berger et al. [12], Boufounou [13], Avkiran [14], and Hensel [15]. The main advantage of regression analysis is that it allows for statistical inference and measurement errors. Comparing with ratio analysis, another advantage of this method is that the influence of multiple independent variables on the dependent variable can be evaluated simultaneously. Regression Analysis provides the average performance information of all branches included in the sample and, for example, can be used for estimating the expected performance of new branches.

While effective in many circumstances (used to measure just about every aspect or to compare similar branches), regression analysis has a number of inherent limitations making it unsuitable for fully reflecting the increasingly complex nature of branch banking. First, regression analysis is a parametric method that requires a general production model to be specified. Second, regression analysis is a central tendency method where predicted values result from a regression model provide the average or expected level of outcome given certain inputs, instead of the maximum achievable outcome [16,17]. Third, it is only suitable to model single input-multiple outputs or multiple inputs-single output systems.

2.3. Frontier efficiency methodologies

The limitations associated with ratio and regression analysis have led to the development of more advanced tools for assessing corporate performance. In recent years, research in this domain has increasingly focused on benchmarking technique based models that can evaluate how well a decision making unit performs relative to the best of their peers if they are doing business under the same operating conditions. An important class of benchmarking methods is the frontier efficiency methodology. The best firms are identified from the data set and they form the empirically efficient frontier. The main advantage of frontier efficiency over other indicators of performance is that it offers overall objective numerical efficiency scores with economic optimization mechanisms in complex operational environments and summarizes the performance in a single statistic [2].

Frontier efficiency techniques can be used in a variety of ways to assist management in evaluating whether they are performing better or worse than their peer groups in terms of technology, scale, cost minimization, and revenue and profit maximization [18]. The resulting information obtained from frontier efficiency analyses can be used to help management identify the operational areas that most need improvement, set future development strategies, identify attractive targets for mergers and acquisitions, and for many other purposes. In addition, achievable targets for inefficient units and the effects of environmental variables can be determined in order to provide additional insights and to improve the overall understanding of their production systems.

In the past three decades, five popular frontier efficiency approaches have been used in bank branch efficiency measurements; three of them are parametric econometric approaches: stochastic frontier approach (SFA), thick frontier approach (TFA), and distribution-free approach (DFA). The other two are nonparametric linear programming approaches: data envelopment analysis (DEA) and the free disposal hull (FDH). These approaches primarily differ in the assumptions imposed on the specifications of the efficient frontier, the existence of random error, and the distribution of the inefficiencies and random error [2,9]. Econometric analyses require an *a priori* specification of the form of the production function, and typically include two error components: an error term that captures inefficiency and a random error. While mathematical, non-parametric methods require few assumptions when specifying the best-practice frontier, they generally do not account for random errors.

Some researchers have comparatively studied the consistency and robustness of the estimations generated by the various frontier techniques, such as, [18–23]. Ferrier and Lovell [24] applied SFA and DEA to U.S. banks to estimate cost efficiency. They found that both techniques generated similar average cost efficiencies, but different decomposition of cost inefficiencies between technical and allocative inefficiencies. Furthermore, the rank-order correlation was particularly weak between SFA and DEA. Bauer et al. [25] investigated extensively the consistency between DEA and the parametric methods: SFA, TFA and DFA. Their conclusion was that although the parametric methods were generally consistent with one another in terms of distributions of efficiency, rank order, and identification the best-practice and worst-practice, the parametric and nonparametric methods were not mutually consistent. Weill [22] also observed the lack of consistency between parametric frontier approaches, SFA and DFA, and the nonparametric approach, DEA, when these approaches were applied on five European banking sectors. However, Resti [21] observed noticeable similarities between SFA and DEA based on the measurements of Italian banks' cost efficiencies. He found that when based on the same data and conceptual framework, the econometric and DEA results did not differ dramatically with a high rank correlation ranging between 72.6% and 88.5%. The most significant difference occurred between the results of the biggest banks. Banker [20] and Banker and Natarajan [23] have shown that DEA estimators had good statistical properties and could be used to provide consistent estimators of the effects of environmental variables on firm performance. Furthermore, Banker and Cummins [18] claimed that DEA could be used more effectively with smaller sample sizes than SFA.

2.4. Other performance evaluation methods

Other performance evaluation methods that have been applied to evaluate bank branch performance include: multivariate statistical analysis [26,27]; analytic hierarchy process [28,29]; gray relation analysis [30]; balanced scorecard [31,32]. Each method has its own advantages and disadvantages.

We found only one study that had compared DEA with other non-frontier analysis techniques on their practical use as performance measurement tools when examining bank branches. Athanassopoulos and Curram [33] compared DEA and neural networks (NN) by using the data from 250 commercial bank branches with multiple inputs and outputs. They concluded that both methods offered a useful range of information regarding the assessment of performance: DEA tended to perform more satisfactorily in estimating empirical production functions and neural networks did rather well as a tool for obtaining relative rankings of DMUs on the basis of their predicted outcomes. The Spearman rank correlation coefficients between DEA and NN varied from 0.36 to 0.68.

3. Summary statistics for DEA applications to bank branches

The reviewed 80 studies are listed in the Appendix and classified according to the following attributes: country/region, inputs, outputs, returns to scale assumptions, and objectivity. To study possible trends over time, we divide the time frame into five 5-year periods, 1985–1990, 1991–1995, 1996–2000, 2001–2005, and 2006–2011. The total numbers of publications in these five periods are respectively 4, 7, 16, 20, and 33, which show a significant increase over time.

Almost all of the bank branch studies were within a single country and only 2 papers [34,35] compared branch performance across nations. Probably due to the quality and accessibility of the data source, the distribution of studied banking sectors is significantly uneven. The top 6 countries, where their bank branches were most frequently studied, account for 65% of our reviewed studies. Out of the 80 published papers, 20 focused on Canadian bank branches, 9 on Greek, 8 on Portugal, 8 on U.S., and 7 on the U.K. The remaining studies were from Cyprus, Czech Republic, France, Germany, Hong Kong, India, Netherland, Queensland, Saudi Arabia, Slovakia, Spain, Sweden, Taiwan, Thailand, Turkey, Iran, and United Arab Emirates.

It is found that the DEA studies in bank branches are mainly focused on two areas: developing more advanced DEA models for branch efficiency analysis (38% or 30 studies), and evaluating management efficiency and providing guidelines for improvement (33% or 26 studies). The study scope also includes: investigating the impact of environmental factors and regional managerial policies on branch efficiency (5); comparing different methods of efficiency measurement (4); examining the impact of branch size on efficiency (3); investigating the trends in efficiency (2); ranking branch performance (2); comparing branch efficiencies across nations (2); investigating the impacts of new technology (2), the impacts of organizational climate on efficiency (2), and the impact of mergers on efficiency (1); pre-processing data to create a sub-sample training data set (1).

4. DEA applications in bank branch research

In 1985 Sherman and Gold [4] wrote the first DEA application paper on bank branch analysis, since then DEA has gradually become a popular benchmarking tool in the banking sector for studying bank branch performance from various aspects. The main research purposes of DEA in bank branch studies are discussed in this section.

4.1. Methodology improvement

Based on our survey, it is found that prior to 1995, the use of DEA in bank branch studies mainly focused on directly applying standard DEA models to assess branch efficiency. Since 1997, the DEA research has gradually shifted towards dealing with both the theoretical extensions and practical applications of DEA. The flexibility of DEA models and the complexity of bank branch operating characteristics offer researchers significant opportunities to develop new models, which are needed in different application situations and with specific purposes. Two lines of research have emerged around the DEA methodology improvement: extending the traditional DEA models and combining DEA models with other advanced operational research methodologies.

Examples of extending traditional DEA models include: Athanassopoulos [36] proposed a two-stage DEA model to embed the value judgments of branch managers for assessing the bank branch operating efficiency and the quality of the provided services; Dekker and Post [37] proposed a quasi-concave DEA model to relax the standard DEA assumptions of concavity for the production frontier; Wu et al. [38] introduced a fuzzy logic formulation into the DEA model to deal with the environmental variables so that the branch performance from different regions could be assessed; Alirezaee and Afsharian [39] introduced a multi-layer DEA model for evaluating branches with extraordinary data; Azizi and Ajirlu [40] evaluated branch performance from both optimistic and pessimistic perspectives and defined both the efficiency and the inefficiency frontier; Paradi et al. [41] proposed a "culturally adjusted" DEA model to benchmark business units that operated under different cultural (business) environments; Paradi et al. [42] proposed a two-stage DEA model to evaluate branch performance from multi dimensions and further integrated these single-dimension efficiency results into an overall efficiency score to allow an overall ranking.

Some studies combined other operational research techniques with the DEA model to make the efficiency estimation more accurate and to extend the model's application scope. Examples include: Cook and Hababou [43] extended an additive DEA model using goal programming concepts to take into account non-volume related activities and simultaneously evaluated the sales, service, and aggregate efficiencies of a bank branch; Porembski et al. [44] visualized the reference and efficiency relationships between the DMUs identified by DEA using Sammon's mapping; Wu et al. [45] presented a DEA–Neural Network study for performance assessment of branches of a large Canadian bank. They claimed that the DEA–NN hybrid model generated a more robust frontier and identified more units that were efficient due to better performance patterns being explored; Lotfi et al. [46] incorporated the decision maker's preference information into the process of a DEA model assessing efficiency using multi-objective linear programming.

4.2. Branch production analysis

Production efficiency is one of most significant dimensions of bank branch performance. In bank branch analyses, the production model commonly views bank branches as producers of services using labor and other physical resources as inputs and providing services for taking deposits, making loans and others (number of transactions or document processing) as outputs. The transactions may be face-to-face with the customer in the branch, carried out in the back office or delivered at customer premises. The branch is a service "factory" and customer satisfaction is also a key outcome of a good effort. Examples include: Sherman and Gold [4]; Paradi et al. [42]; Parkan [47]; Oral and Yolalan [48]; Vassiloglou and Giokas [49]; Giokas [50,51]; Oral et al. [52]; Drake and Howcroft [53,54]; Athanassopoulos [36,55]; Camanho and Dyson [56,57]; Portela and Thanassoulis [58]; Schaffnit et al. [59]; Cook and Zhu [60].

4.3. Branch profitability analysis

Profitability is the measure of how well branches generate profits from their use of labor, assets and capital. It treats the branch as the producer of a product as opposed to the provider of a service. While this does simplify the identification of inputs and outputs there are still some complexities to address. There is the issue of separating some revenues from their products. For example, a bank provides a below prime interest loan to a customer but requires that a certain percentage of the funds lent be held in the bank account (which pays minimal or no interest to the customer). This results in certain products appearing more profitable because the customer is paying interest on money that the bank has not released in practice. In this case, there is lower lending revenue (because of the below prime interest rate) but higher commercial banking revenue from the interest earned on the portion left on deposit at the bank. Examples of such studies include: McEachem and Paradi [35]; Paradi et al. [41,42]; Manandhar and Tang [61]; Al-Tamini and Lootah [62].

4.4. Branch intermediation analysis

The branch's intermediary role is mainly studied to examine how efficient the branch is in collecting deposits and other funds from customers (inputs) and then lending the money in various forms of loans, mortgages, and other assets (investments). A branch's intermediation efficiency is a strong indicator of the strength of its lending ability, which is, in turn, directly tied to a bank's ability to operate as a going concern. Loan quality and losses are critical factors in a bank's health. The majority of research on the causes of bank failures found that there was a strong relationship between the proportions of non-performing loans and bank failures [63]. Hence, loan losses are usually included in the model, but on the input side, to appropriately reward those with small loan losses. On the other hand, too low loan losses may also be a problem because that implies that the bank is also passing up good business by being overly restrictive in its credit criteria. Camanho and Dyson [57] evaluated branch efficiency with production and intermediation (value-added) models. They concluded that the joint use of the production and value-added approaches was a powerful tool for generating a comprehensive assessment of bank branch efficiency. Paradi et al. [42] shed much light on the branch's intermediation efficiency using data from 816 Canadian bank branches. The relationship between the intermediation efficiency and productivity and profitability were examined. They also investigated the impacts of branch location and size on the branch's intermediation efficiency.

4.5. Branch cost efficiency analysis

Cost efficiency evaluates the ability of a branch to produce current outputs at minimal cost. It is the result of technical efficiency and allocative efficiency. The measurements require the input and output quantity data as well as the information of input prices at each branch. There are several examples in this research area. Athanassopoulos [55] assessed the cost efficiency of 580 U.K. branches by splitting branches into homogenous clusters based on the factors reflecting the branches' environment and operations. Camanho and Dyson [64] estimated the upper and lower bounds of branch cost efficiency measures under price uncertainty scenarios. Camanho and Dyson [65] developed a DEA model to evaluate branch cost efficiency by considering non-homogeneous inputs and different prices. Noulas et al. [5] examined the cost efficiency of branches in six major Greek cities and investigated the effect of size on cost efficiency.

4.6. Efficiency ranking

To target branches in most need of assistance, branch efficiency ranking is also one of the interesting research areas in DEA applications. Yavas and Fisher [66] evaluated and ranked the operational performance of bank branches in terms of branch productivity. Alirezaee and Afsharian [67] fully ranked the efficient and inefficient branches using DEA efficiency scores and a "balance index". Paradi et al. [42] developed a two-stage DEA model to generate a more acceptable ranking score based on multi-dimensional performance measurements.

4.7. Branch studies incorporating service quality

There are mainly two ways to incorporate service quality factors into branch performance analyses, either directly into the DEA model or conducting post-hoc analyses on the relationship between the DEA efficiency scores and the service quality reported. Golany and Storbeck [68] incorporated customer loyalty and customer satisfaction into their DEA model as outputs to evaluate the bank branch performance by seeing the bank as a provider of financial services. Soteriou and Stavrinides [69,70] incorporated service quality as an output to provide suggestions towards internal customer service quality improvements. Sherman and Zhu [71] developed a multi-stage DEA model to incorporate quality measures into the DEA efficiency analysis. Athanassopoulos [36,72] conducted a post-hoc analysis to capture the impacts of service quality on branch operating efficiency. Soteriou and Zenios [73] and Portela and Thanassoulis [58] investigated the links between service quality and branch operating and profit efficiency.

4.8. Environments and technology impacts on branch performance

Traditional DEA models are designed to evaluate the relative efficiencies of production units that operate in similar operating environments, otherwise, the efficiency analysis may lead to an unreliable economic conclusion. The requirement for a homogenous operating environment limits the application of DEA in many real-world cases. Some researchers have noticed this limit and introduced several different strategies to estimate managerial inefficiency by accounting for the exogenous impacts, such as the impacts of locations, market power, regulations, organization, and new technologies. In general, the studies on the impact of exogenous factors can be classified into four broad categories according to their main research purposes: (1) cross-country branch comparison, (2) cross-bank branch comparison, (3) cross-region branch comparison within a single bank, (4) investigations on the impact of some specific exogenous factor, such as technology innovations.

Increasingly, globalized financial markets with considerable activity in the multinational sector have stimulated the need for cross-country bank branch performance comparisons. However, this topic is relatively unstudied due to the lack of congruency in economic, regulatory, cultural, and customer service environments. Although the last ten years yielded considerable progress in international comparisons at the institutional level, only one study has focused on branch-level efficiency comparison. McEachern and Paradi [35] assessed bank branch profitability and productivity across seven national branch networks operated by a multinational financial services corporation. Due to the very similar management culture (e.g. product lines, training programs, corporate values and goals, information technology systems, etc.) imposed on the seven banks by their common owner, the corporate disparity was removed and that allowed the researchers to examine the effects of the national culture on bank branch performance. Input-oriented CCR profitability and productivity models were run domestically for each country and the best performers from each country were included in the regional profitability model. The authors concluded that countries in which branch performance was quite consistent amongst domestic branches were less productive and less profitable when compared to other countries that had more disparity in their efficiency scores.

Branch data is considerably more difficult to obtain from competing banks, and is not compiled by government organizations for any monitoring purposes [35]. Furthermore, different banks tend not to define data representing a certain activity or item in exactly the same manner. For example, "assets" may mean generally the same thing, but in fact, there are different components included depending on the banks' own decision or even by legislation, which complicates cross-bank analyses. There are limited studies to quantify the effects of the whole organizational management on the relative performance of branches that come from different banks. Yang and Paradi [74] might be the first ones to examine the influences of corporate policies on branch efficiency in the DEA context. A "handicapping factor" was introduced to quantify the differences between three Canadian banks' management policies. The branches operating under unfavorable head office policies were compensated by reducing their inputs (or increasing their outputs) using a "handicapping factor", and the branches enjoying advantageous conditions were handicapped by increasing their inputs (or decreasing their outputs). In another study, Paradi et al. [41] proposed a culture-adjusted DEA model to benchmark the relative performance of branches coming from two different banks. Two cultural indices, each representing a specific aspect of the bank's top management, were derived to capture the firms' cultural influences, which were beyond the control of the branch managers. The CA-DEA model's solution has several characteristics: (1) the environmental factors are directly incorporated in a DEA model without increasing the number of inputs or outputs; (2) only the DMUs with poor environmental conditions can be compensated; (3) the underlying assumption of the CA-DEA model is that the effects of operating environments are actually externally imposed on a DMU's whole production process, i.e. the overall relationship between inputs and outputs, instead of on individual input/output.

There are a number of studies measuring the effects of the differences in the regional characteristics on branch efficiency within the same bank. Das et al. [75] measured the branch-level labor-use inefficiency of a single bank across India's four biggest metropolitan cities. An area or spatial efficiency was calculated for each region relative to the nation as a whole. They found that the policies, procedures, and incentives handed down from the corporate level could not fully neutralize the detrimental influence of the local work culture across different regions. Deville [76] applied DEA to a French banking group to conduct an intra- and inter-regional benchmarking analysis. The 1611 branches were split into six trade environments, and one efficiency frontier was determined for each type of environment, and then the results were split into 16 regions. The inefficiency scores of individual branches were aggregated to evaluate the regional groups. However, this study did not provide an in-depth discussion about the effects of location on branch activity.

Technical revolution has led to new channels through which financial products and services can be delivered. Customer flows have also been redirected and the role of bank branches is evolving. Cook et al. [77] studied the change in performance that branches underwent when moving from the old to the new structure where transactions were automated. They concluded that e-branches (new structure) did not exhibit productivity gains when compared to both the best practices of the traditional branches and the e-branches' predecessors. However, Meepadung et al. [78] through applying a two-stage DEA model explored the impact of IT-based retail banking services on branch efficiency, and found that IT-based transactions at the branch level had a significant impact on profit efficiency.

4.9. Effects of mergers and acquisition on branch performance

The effects of mergers and acquisitions on branch efficiency have been less intensely investigated. How the efficiency effects of mergers and acquisitions on the branch level differ from the bank merger studies that rely on externally reported financial data on the entire bank's performance was examined. Only one study has been found applying DEA to this issue. Sherman and Rupert [79] analyzed merger benefits and identified cost savings opportunities based on the comparison of branch operating efficiencies in the merged bank and four pre-merger banks. They found that mergers could generate added profits from synergies and scale economies, supporting the value of the mega-merger trend. Furthermore, rapidly and effectively developing and adopting consistent operating and control systems across the merged bank entities would help to improve the merged bank's performance.

To provide an internal view of the potential economies of scale and synergies that may result from mergers further research could contribute significantly to both the bank merger decision making and following process improvement.

4.10. Unusual banking applications of DEA

In addition to the application areas discussed above, DEA has also been applied to solve some specific problems. Nash and Sterna-Karwat [80] using DEA measured the effectiveness of cross-selling financial products among 75 bank branches in Australia. Soteriou and Zenios [73] examined the efficiency of bank product costing at the branch level. Their study focused on allocating total branch costs to the product mix offered by the branch and obtaining a reliable set of cost estimates for these products. Stanton [81] investigated the relationship managers' efficiencies at the branch level in one of Canada's largest banks. Jablonsky et al. [82] proposed a DEA model for forecasting branch future efficiency bounds based on interval input–output data from the bank management's pessimistic and optimistic predictions. Wu et al. [45] applied a DEA model as a data filter to create a sub-sample training data set used for neural networks to evaluate branch efficiency.

5. Model building related findings

Since a large number of DEA models are available, practitioners using DEA to study bank branch issues will inevitably face the problem of deciding which specific DEA version to apply and face the dilemma of selecting the appropriate inputs and outputs. Although there is no commonly agreed rules on how to make these decisions, a systematic summary with particular references is very useful.

5.1. Problem definition

Before bank branch efficiency can be measured, a definition of what its business processes are is required. Countless studies have been done to attempt to define accurate ways of measuring bank (branch) efficiency. Kinsella [83] discussed some of the reasons why the efficiency measurement in the banking sector was difficult: complex services and products were offered, many of which were interdependent; some provided services were not directly paid for; and complex government regulations might affect the way in which services were offered or priced. Given these issues, it becomes obvious that there is no one single perfect model capable of fully capturing the multi-role nature of bank branches and that clearly a combined set of metrics is required to accurately measure bank branch efficiency.

In the real business world, branch managers may choose to focus on only one or two aspects of their branch as part of a competitive or purely responsive strategy based on their specific operating environments. A branch attempting to improve its lending results (or intermediation efficiency) could potentially lower their production efficiency. For example, to improve their average loan quality and reduce loan defaults, a branch may choose to increase the number of loan officers and the amount of time they spend with each client. However, this may well have a negative impact on the branch's production efficiency, as there is an increase in staffing (additional loan officers) combined with a decrease in the rate of transactions performed (due to more time being spent with each client). Additionally, there could also be adverse effects on profitability (due to the increased staffing costs) if there was not a subsequent reduction in loan losses to offset the cost increase. Due to this complex situation, many researchers applied more than one DEA model simultaneously to evaluate branch performance and identify the improvement opportunities in each dimension. Examples include: Paradi et al. [42], Giokas [51], Portela and Thanassoulis [58], Al-Tamimi and Lootah [62], Sherman and Ladino [84]. Some researchers viewed the production process as a multi-stage process. Seiford and Zhu [85] separated a commercial bank's production process into two stages, profitability and marketability. Two DEA models connected in series were employed to evaluate the bank's efficiency.

Most models can be processed either as input oriented or output oriented and sometimes both are carried out for the same model. The production model is not a typical candidate to be used in an output-oriented analyses because the branch cannot do much, if anything, about getting customers into the branch to do business [42]. Radial efficiency measures, which adjust inputs or outputs proportionally, are the most widely used in such studies. It is found that only 8 out of 80 reviewed studies use the additive or slacks-based-measure DEA model, while 72 of them apply the CCR or BCC model.

5.2. Inputs and outputs selection

To serve different research objectives, the input and output selections are typically different in these studies. In general, appropriate inputs are the measures that the DMUs would like to minimize, while outputs are the measures that DMUs would like to maximize. Based on the available data set, the first step is to list all possible inputs and outputs that may be related to the study. These inputs and outputs can be further examined by some screening procedures such as preliminary judgment and statistical analysis in order to retain only the most relevant ones. According to the number of DMUs and study purposes, different levels of data aggregation or disaggregation have to be conducted. For example, staff can be treated as a single input in numbers [82,86–88], or disaggregated into several different types, such as service staff, sales staff, support staff, and other [42,59,74,85,89]. A certain degree of aggregation is necessary to reduce the number of constraints and then help increase the model's discrimination.

However, there is a question about what to do with an input or output that should not be minimized or maximized, respectively. One example of these is bad loans, which is obviously an output, but it is not desirable to reward the DMU (a branch here) for having more bad loans than its peers have. Three different approaches have been used in the literature. The first is to leave bad loans as an output but use the inverse value. The second method is to move it to the input side where the lower this value is, the better [42,46,90]. Fukuyama and Weber [91] and Akther et al. [92] employed a two stage DEA network production model to evaluate bank's performance, where the bad loans that were generated in one period were treated as an undesirable input to the first stage of production in a subsequent period. The third one is to treat bad loans as undesirable output with an assumption of weak disposability, which requires that undesirable outputs can be reduced, but at a cost of fewer desirable outputs produced [93]. Only one study has tested the effects of including bad load related factors. Gaganis et al. [94] used two DEA models to estimate branch profitability, one with the loan loss provision as an input and the other without loan loss provision. They found that the differences between these two specifications were statistically significant based on a Kruskal–Wallis test and that risk was an important factor for the estimation of branch efficiencies.

The role of deposits is another controversy. On one hand, it could be argued that the higher the value the better because that shows "efficiency" in attracting depositors. On the other hand, one could make a case that the lower the deposit value, the better, because the bank is doing more lending with less deposits (on which they have to pay interest). This, of course, implies that the bank has sources of funds that are cheaper than deposits. Fortunately the analyst can have it either way, but also both ways if there are several models being built, depending on what the model is intended to achieve. Fixler and Zieschang [95] claimed that the deposits were consistently positioned as an output under the user cost approach. Based on our reviewed 80 papers, it is found that 5 studies used the value of deposits as input and 43 studies as output. And 4 studies used interests paid on deposits as an input.

5.3. Returns to scale characterization

In general, in bank branch efficiency analysis, DEA model can be applied by assuming either constant returns to scale (CRS) or variables returns to scale (VRS). The selection should be guided by the production function or practice. Based on the reviewed 80 studies, 47% used the CCR assumption, 20% used the BCC assumption, and 33% used both. Camanho and Dyson [57] concluded that for the bank branches under analysis, the frontier of the production possibility set should be estimated assuming VRS for the production approach, and assuming CRS for the value-added approach. Paradi and Schaffnit [96] claimed that provided commercial and specialty (oil and gas and real estate) branches were excluded, bank branches were found to operate using a constant returns-to-scale technology.

5.4. Sample size issue

DEA, as many other methods, requires that there be enough observations to allow good separation and discrimination between DMUs. Several methods can be used to address this problem. One is to increase the number of DMUs using the Windows analysis approach, which allows different years' observations to be compared to each other. Another possibility is to decrease the number of inputs and outputs in the models and then creating more than one model where each has fewer total (inputs + outputs) number of variables. Adler and Golany [97] combined principal component analysis (PCA) with DEA to reduce the effects of the "curse of dimensionality". Here, PCA aims to find the uncorrelated linear combinations of original inputs and outputs, and therefore to improve discrimination in DEA with minimal loss of information. Jenkins and Anderson [98] used partial covariance analysis to identify those variables that could be omitted with the least loss of information as measured by the proportion of total variance in all the variables lost by omitting particular variables. In general, the number of DMUs should be at least three times the total number of inputs plus outputs used in the models. So, for example, if there are three inputs and five outputs, the minimum number of DMUs should be 24. This is a rule of thumb decision without scientific backing but from a practical point of view, works reasonably well [98]. Often another similar rule can offer guidance as follows: $n \geq \max\{m \times s, 3 \times (m+s)\}$, where n = number of DMUs, m = number of inputs and s = number of outputs [99].

Al-Faraj et al. [100] applied the basic formulations of DEA to assess the performance of 15 bank branches in Saudi Arabia. They used eight inputs and seven outputs, and subsequently identified all but three branches as relatively efficient. They inadvertently illustrated one of the limitations associated with DEA usage: its inability to effectively discriminate between efficient and inefficient units when a limited number of observations, relative to the number of input/output variables, were used. Examples of studies using large sample size can be found in Deville [76], 1611 French branches; Cook et al. [77], 1200 Canadian branches, Paradi et al. [42], 816 Canadian branches; Wu et al. [38], 808 Canadian

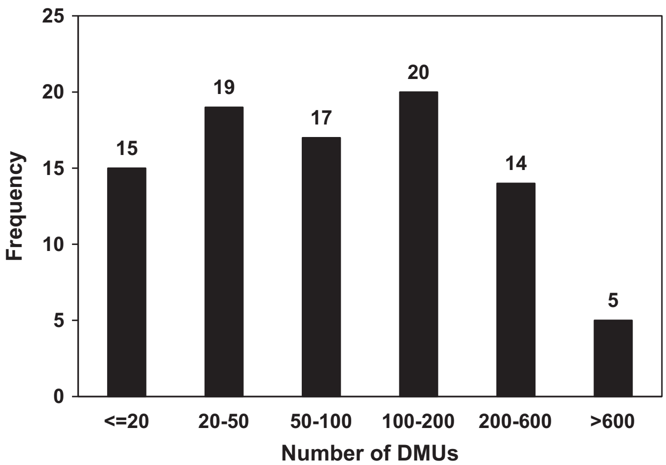

Fig. 2. Frequency distribution of the sizes of the data sets that have been used in the papers studied here.

branches. The frequency distribution of the sizes of data sets that have been used in the 80 reviewed papers is presented in Fig. 2.

5.5. Variable relationships and proxies

Data may be available on measures that really represent the same variable, although often expressed in different units. An example of this is staff in a branch. Some studies measure this variable in personnel related expenses [5,61,101,102], some in working hours [49,72], and some in full time equivalent employee numbers, as discussed in Section 5.2. Since these measures represent the same variable, labor, typically only one is used and the decision should be dictated by the objectives of the study. More often the FTE measure is used because it eliminates the dispute over pay scales that may be different depending on the local economic realities (large city vs. small community). However, if the manager has the flexibility of using staff in different capacities—less costly workers assisting a more costly one (really good sales people receive more support), the salary costs may be a better measure to bring out the efficiency gained by more effective management of the resource.

But there are other situations where different variables prove to be very highly correlated, even if they are not related logically. In this case, we may consider one as the proxy of the other. And it is appropriate to use only one of the measures because the highly correlated other(s) only decrease the discriminatory power of the model without adding useful information. Hence, it is customary to first run correlation analyses on all inputs and outputs selected for the model to see if one or more are highly correlated and then decide which may be dropped from the model. One might also take into consideration suspected relationships between certain input(s) and output(s) and test them to ensure that those that do correlate are left out of the analysis as appropriate. A practical comment: it is always better to choose the variable that management sees as more representative of their view of the units' production model—this tends to help with their acceptance of the results.

5.6. Data issues

When datasets are obtained from real operations, often we find a number of data items which are "blank". This is different from an entry that is actually zero because that means that the DMUs deliberately use or produce zero quantities of the input/output. A blank may mean zero, N/A (not available) or simply "we do not know". If there is no information or guidance from the data source about how to deal with these data items, the associated DMUs must be excluded from the analysis. If they are included, then there must be an agreement by everyone that whatever is used (zero, for example) is acceptable.

One possible way to deal with zero entries in the data set is to add a small fixed constant. However, Nash and Sterna-Karwat [80] found that the data set containing many zero entries could distort the branch analysis even if a small fixed constant had been added to these zeros. Furthermore, in this situation the capability of DEA to identify trade-offs was lost. They introduced an additional output in the form of a count for non-zero entries and proposed a subsequent amendment to the DEA additive model to reduce the impact of the zeros on the analysis. They claimed that the produced results could reflect the real business case. However, they were not clear whether the "count" constraint for inputs would help to overcome the same problems which might stem from zero input entries.

5.7. Branch group issue

Retail branches are often segmented based on their business environments, such as: small rural (small towns and villages), small urban (local residential areas in large towns and cities), large rural or regional (located in larger towns and some branches serve local businesses as well), major urban (large cities, sophisticated clientele, investment and business orientation). Deville [76] split their studied branches into 6 business environments based on the criteria of proportions of employee assets in agriculture, employees, businesses, executives, senior citizens, second homes, homeowners, unemployment rates, and rates of population growth. This kind of segmentation was often employed in DEA studies of larger banks where there were a sufficient number of branches and across wide demographical areas. Unfortunately such distinctions are often the cause of inaccurate results because geographical location is not necessarily a good factor to decide the similarity of their operating environments. Paradi et al. [103] addressed this grouping issue and proposed a novel grouping approach in a DEA context to identify branch managerial groups based on their operating patterns. This proposed model was tested on a big Canadian bank branch network with 962 branches and further compared with the results obtained from traditional community type and population size' grouping criteria.

5.8. Too many DMUs on the frontier

Bank branches tend to be very well managed, or at least well controlled, as they have to follow often stringent policies and rules laid out by their Head Office and the Government regulator. This results in a substantial portion of the branches being on the efficient frontier, typically 25–50%. While this is not a problem with the technique per se, it is a problem if management wishes to improve operations across the branch network because frontier resident branch managers see themselves as already being the best they can be. Sowlati and Paradi [104] addressed this issue by developing a management opinion based technique that created a "Practical Frontier" that enveloped the empirical one, thus offering targets to the empirically efficient units. The data set including 79 bank branches was used to illustrate the applicability of this approach.

5.9. Environmental factors

To generate reliable and acceptable branch efficiency estimations, the effects of "external" factors, which can affect a branch's operational processes but are beyond the branch manager's control, should be adjusted. Fairness and equitable treatment are two key components that affect the results' acceptance. These external factors can be classified as environmental factors. Fethi and Pasioras [1] and Paradi et al. [41] discussed various approaches that had been used to control environmental impacts on DEA efficiency measurements.

In the published DEA applications, there are mainly two types of environmental factors from a branch management point of view: region-specific and corporate-specific. Examples of the region specific factors may be the local economic growth rate, local community types, different opening hours, local unemployment rate, etc. Another such factor, which is more difficult to quantify but is very important, is the competitive environment the branch operates in. Clearly, if the branch is the only one in town, it gets almost all the business, but if it is located across the street from three other bank branches on the same intersection and has two or three others within a block, it has to fight for its market share. A possible way to include this factor is to develop a "competitive index" as was done by Vance [105]. She incorporated in her index the type and number of competitors in the reasonable geographical drawing area of a branch. Paradi and Schaffnit [96] evaluated 90 commercial branches of a large Canadian bank, across eight economic districts in Canada by incorporating economic conditions in the models. The regional economic data was obtained from the examined bank's economics department and represented the average rate of change of the real regional domestic product. This factor was used to avoid unfair comparisons between branches operating in the economically disadvantaged region to their counterparts, where the economic conditions were a lot more favorable.

When one compares branches across banks, the corporate-specific differences should be considered, as top management tends to determine what segment of the banking business they want to focus on. Of course, all banks do a lot of the same things, loans, deposits, mortgages, etc., but they also specialize in some areas such as trading gold metal, discount securities brokerage, foreign exchange trading and others. Hence, some methodology must be introduced to allow for the systemic differences caused by the managerial direction the branches are getting. Paradi et al. [41] proposed a culturally-adjusted DEA model to control the corporate culture's impacts on cross-bank branches' efficiency comparison. Two cultural indices were designed to represent two aspects of a firm's unique operating environment. The corporate index (CI) was designed to capture the nature and the impact of a firm's corporate strategies, including resource allocation processes and product portfolios construction, which would in turn impact the branches' ability to coordinate their operating activities and optimize product diversity. The service capacity index (SI) was calculated as a combined index of the branch's average daily working hours, branch size, branch age, and the number of automated teller machines. It was assumed that these factors could affect a branch's overall service delivery capacity but were determined by the bank's top management. Seiford and Zhu [85] developed a context-dependent DEA model to measure the attractiveness of a bank against its competitors with regard to a bank's profitability and marketability.

5.10. Validating results

For most managers, DEA is an unknown "black box" and without meaningful validation they will not use it or believe in the recommendations offered on the basis of such results. Hence, validation of the results is important. One method is to compare DEA results with the bank's own performance measures. Managers are interested in improving their operations but whatever measurement methods are used to evaluate performance needs to be validated against other methods or even just against the managers' experience or expectations of how their world works. Formal validation is a critical success factor in having the results of an analysis accepted by those who are being measured.

Techniques comparison is another way to validate DEA results. There are some examples comparing DEA results with other efficiency evaluation methods. Giokas [50] compared the operational efficiency obtained from DEA and log-linear deterministic frontier model using 17 Greek bank branches. They found that the results of the two methods did not exhibit significant differences. Parkan and Wu [106] compared the operational competitiveness rating analysis method and DEA ratings and profit scores through examining the impact of the incremental costs of hiring additional was on branch performance. They concluded that the similarity between the DEA and operational competitiveness analysis rating profiles grew as the restrictions on DEA's relative cost and revenue category importance weights were tightened.

The third approach is to conduct Monte Carlo simulations to examine the performance of the DEA model. Monte Carlo experiments are a class of computational algorithms that rely on repeated random sampling to compute the results. Paradi et al. [42] used Monte Carlo simulation experiments to prove how well their proposed culturally adjusted DEA model dealt with the environmental effects present and to compare the performance of the culturally adjusted DEA model with that of the other two alternative DEA models, the traditional non-restricted DEA model and the DEA model using non-controllable variables.

6. Suggestions for further research

DEA has been treated in most application studies as a deterministic technique but the DEA results are sensitive to the dataset used. Therefore, to provide statistical inference or confidence intervals for the efficiency estimations it would be very useful to prove the model's reliability and acceptance. During the past 20 years, various statistical tests have been pursued to improve the reliability of managerial and policy implications of DEA studies, but this should still be an important area for future research due to the flexible structure of DEA models. There are mainly two lines of research in this area. One is analytical where the deviation from the DEA frontier is viewed as a stochastic variable. Banker [20] showed that DEA provided a consistent estimator of arbitrary monotone and concave production functions if the deviation of actual output from the efficient output was regarded as a stochastic variable with a monotone decreasing probability density function. The second approach was illustrated by Banker and Natarasan [107] who discussed several statistical tests for efficiency comparison of groups of DMUs, for the existence of scale inefficiency or allocative inefficiency and for input substitutability. However, these tests need to be used with caution in small samples. But there is another approach that is empirical that re-samples DEA efficiencies to approximate the distribution of the DEA efficiency and conduct statistical inference. Simar and Wilson [108] applied bootstrapping methodology to conduct sensitivity analysis on DEA efficiency scores. However, there is no published application of statistical tests in DEA bank branch studies.

Branch efficiency analysis has shown that there are always inefficient areas existing in some operating processes, but few studies discussed in detail the underlying causes of these deficiencies and how to reduce wasted inputs and increase desirable outputs in practice. More practical advice in line with financial theory would be helpful to encourage the applications of DEA in the real business world.

Although there have been many research thrusts in DEA techniques over the past four decades, there is still no reliable DEA model that can effectively handle the situations where some variables are mixed with both positive and negative entries. However, in real situations such as the bank branch application, data entries can often be both positive and negative and therefore it is of interest that effective approaches for DEA efficiency measurement are developed to deal with such data set.

DEA is a significant tool in banking sector analysis because it does not need preconceived models and can be adapted to many views. But it also has inherent limitations, so another interesting future research area is to find new ways to apply DEA in conjunction with other advanced methodologies in order to extend such methodologies and to complement each other's strengths while eliminating their weaknesses. For example, Giokas [109] tested the use of DEA, regression analysis, and goal programming as a means for determining the efficiency of simulated organizational units. He found that the most reliable results were derived from the combination of DEA with goal programming.

7. Conclusions

DEA became a main stream technology in bank branch studies in recent years. However, there is a lack of a literature review in this field. Bank branches are typically well managed and collect copious amounts of data on very detailed operational activities. They offer an almost ideal study subject for DEA researchers. In this paper we present the results of a survey of 80 DEA applications published in journals since 1985, all known (to authors) studies in this area.

Our survey find that methodological improvements account for the majority of DEA studies on bank branches, and that is followed by the research area of benchmarking branch performance and identifying the sources of inefficiency. The methodology improvements designed to solve problems associated with bank branches include: multi-dimensional performance evaluation, serving the needs of both branch and senior management; incorporating the decision makers' knowledge into the efficiency assessment process; adjusting organizational culture differences during the efficiency analysis across firms; dealing with non-homogeneous inputs; building efficient standards into the DEA analysis; relaxing the assumption of concavity for the production frontier; multi-layer DEA models for extraordinary data; and generalizing DEA models to deal with interval data. Production efficiency, profitability, intermediation efficiency and cost efficiency account for the most widely studied aspects of branch performance.

From a methodological aspect, we find that there is significant diversity among studies in terms of the input/output selection. Constant returns to scale assumption and the radial efficiency measures are still the most widely used approaches. In addition, there has been a growing interest in the incorporation of environmental considerations into the DEA models in recent years. Based on our survey, some key issues on the building of appropriate DEA models are discussed, as these could be helpful to researchers interested in using DEA to study bank branches. Due to the wide concerns on how to continue to be competitive in the increasingly dynamic business environment, developing more reliable DEA models will continuously be an important topic in bank branch studies.

In summary, it can be seen that there are many reasons for stimulating the analysts' ingenuity in formulating appropriate DEA models. Most real-life issues are usually less than ideal (from an analytical or theoretical point of view) hence an analyst must innovate in order to use what data is available to come up with the answers required by management. The comparisons of efficiency scores obtained from the DEA model with other efficiency evaluation methods show mixed results. Given the importance of bank branch modeling techniques and the focus on performance improvement, we believe that the basic DEA models as well as their many extensions would likely play a more important role in bank branch studies in future.

Appendix

See Table A1 for more details.

Table A1

Author	Country/region	# of DMU	Input	Output	Model	Objectives
Al-Faraj et al. [100]	Saudi Arabia	15	Employees, percentage of employees with college degree, average working experience, location index, authority index, decoration expenditure, average salaries, other operational expenses, acquired equipment	Monthly average net profit, monthly average balance of current accounts, monthly average balance of savings accounts, monthly average balance of other accounts, monthly average of mortgages, loan index, no. of accounts	CRS	Evaluate branch's efficiency in order to improve their service quality and utilize the available resources more efficiently
Alirezaee and Afsharian [39]	Canada	79	Sales staff, service staff, other staff	Loans, mortgages, registered retirement saving plans, letter of credit	CRS	Fully rank the efficient and inefficient branches using efficiency score and 'balance index'
Al-Tamimi and Lootah [62]	United Arab Emirates	15	Model 1: operating cost, interest costs; Model 2: interest expense, employees' expenses, other operating expenses	Model 1: interest income, total loans, total deposits, non-interest income; Model 2: interest revenue, non-interest revenue	CRS	Investigate the branch operating and profitability efficiency
Angiz et al. [110]	U.S.	14	Rent, FTE staff, supplies	Loan, changes in account number, travelers checks + bonds sold + bond redeemed, deposits	CRS	Introduce a mathematical method for improving the discrimination power of DEA and to completely rank the efficient decision-making units using fuzzy concept
Asmild and Tam [34]	7 countries	115	Remuneration, interest costs, other expenses	Interest revenue, non-interest revenue	CRS	Based on Malmquist indices to calculate frontier differences between bank branches in different countries
Athanassopoulos and Curram [33]	U.K.	250	No. of automatic facilities, trained personnel to sell financial products, no. of counter transactions, estimated potential market	Loans sales, liability sales, investment and insurance policies sold	CRS, VRS	Investigate the merits of DEA and neural networks as tools for assessing efficiency of decision making units
Athanassopoulos [36]	Greece	68		Model 1: deposit accounts, credits transactions, debits transactions, loan applications,	VRS	Propose a two-stage DEA model to embed the value judgments of branch managers for

			Model 1: no. of employees, online and ATMs, no. of computer terminals; Model 2: total non-interest costs, total interest costs	transactions with commission; Model 2: volume of loans, time deposit accounts, saving deposit accounts, current deposit accounts, non-interest income		assessing the bank branch operating efficiency and the quality of the provided services
Athanassopoulos [55]	U.K.	580	Model 1: no. of transactions, potential market, sales representatives, internal automatic facilities, branch outlets in the surrounding area; Model 2: direct labor costs, total technology facilities	Model 1: liability sales, loans and mortgages, insurances and securities, no. of cards; Model 2: no. of transactions, liability sales, loans and mortgages, insurances and securities, no. of cards	CRS, VRS	Propose two models for assessing the branch market and cost efficiency. To increase the validity of the evaluation, the bank branches are split into homogenous clusters based on the factors reflecting the branches' environment and operations
Athanassopoulos and Giokas [72]	Greece	47	Model 1: labor hours, branch size, computer terminals, operating expenditure; Model 2: labor costs, operating expenses, running costs of the building	Model 1: deposit and transfer transactions, credit transactions, foreign receipt transactions; Model 2: savings deposits, current deposits, demand deposits, time deposits, total loans, and non-interest income	CRS, VRS	Summery the experimental results by applying DEA technology to assess bank branch performances during the period of 1988–1994
Avkiran [86]	Queensland	65	Non-discretionary inputs: average annual family income, no. of small business establishments, presence of competitors; discretionary inputs: no. of teller windows in branch, no. of staff, staff conduct	No. of new deposit accounts, no. of new lending accounts, no. of new investment center referrals, fee income	VRS	Examine the branch efficiencies, showing that accounting variables could be complemented by non-accounting variables controllable by management
Azizi and Ajirlu [40]	Iran	50	Branch floor area, no. of computers, no. of personnel	Mortgage account, premium, counter level of deposits, loans	CRS	Evaluate branch performances from both optimistic and pessimistic perspectives. The optimistic efficient branches collectively delineate an efficiency frontier, while all pessimistic inefficient branches define an inefficiency frontier
Bala and Cook [111]	Canada	180	No. of employees, (flexible variables: total accounts opened, no. of deposits/transfers, no. of withdrawals/updates)	No. of retirement savings plans sold, total loans	CRS	Present an additive DEA model to incorporate expert knowledge for evaluating branch performance
Camanho and Dyson [56]	Portugal	168	No. of employees, floor space, operational costs, no. of external ATMs	No. of general service transactions performed by branch staff, no. of transactions in external ATMs, no. of all types of accounts, value of savings, value of loans	CRS	Employ DEA to complement the profitability measure and investigate the effects of branch size on efficiency and target setting
Camanho and Dyson [64]	Portugal	144	Production model: no. of branch/account managers, no. of administrative/commercial staff, no. of tellers, operational costs. Input prices: salary of branch/account managers, salary of administrative/commercial staff, salary of tellers. Value-added model: non-interest costs, interest costs from deposits, interest costs from loans	Production model: deposits, loans, off-balance sheet business, no. of general service transactions. Value-added model: deposits, loans, off-balance sheet business. Output prices: fund transfer price of deposits, interest earned from loans, income from off-balance sheet business	CRS, VRS	Develop a DEA model that enables a simultaneous evaluation of input usage and output production with a cost minimization objective. Evaluate branch efficiency with production and value-added (intermediation) models
Camanho and Dyson [57]	Portugal	144	No. of branch and account managers, no. of administrative and commercial staff, no. of tellers, operational costs. Input prices: average salary and fringe benefits of branch and account managers, average salary and fringe benefits of administrative/commercial staff, average salary and fringe benefits of tellers	No. of general service transactions	CRS	Improve DEA cost efficiency measurements under price uncertainty scenarios by estimating the upper and lower bounds of the CE measures
Camanho and Dyson [65]	Portugal	39	No. of branch and account managers, no. of administrative and commercial staff, no. of tellers, operational costs	Deposits, loans, off balance sheet business, general service transactions	CRS	Develop a DEA model to evaluate branch cost efficiency considering non-homogeneous inputs and different prices
Camanho and Dyson [88]	Portugal	144	No. of employees, operational expenses	Value of savings, value of loan, other revenues, no. of transactions	CRS	Based on the Malmquist index evaluate branch performance for the comparison of within-group efficiency spread, evaluate internal managerial efficiencies, the comparison of frontier productivity, reflecting the impact of environmental factors and regional managerial policies on branches' productivity
Cook and Hababou [43]	Canada	20	Model 1: no. of service staff, no. of support staff, no. of other staff; Model 2: no. of sale staff, no. of support staff, no. of other staff	Model 1: no. of menu account transactions, no. of visa cash advance, no. of commercial deposit transactions; Model 2: no. of RSP account	CRS, VRS	Extend the DEA additive model using goal programming concepts to take into account non-volume related activities and evaluate

Table A1 (*continued*)

Author	Country/region	# of DMU	Input	Output	Model	Objectives
				openings, no. of mortgages transacted, no. of variable rate consumer loans transacted		simultaneously the sales, service, and aggregate efficiencies of a bank branch
Cook and Zhu [112]	Canada	100	Sales staff, service staff, other staff	Service output, sales output	CRS	Develop a procedure to incorporate performance standards directly into the DEA structure
Cook and Zhu [60]	Canada	100	Sales staff, service staff, other staff	Deposits, account openings, withdrawals transactions, passbook updates, transfers, visa cash, no. of registered retirement savings plan account opening, letters of credit, loans opening accounts	CRS	Utilize the DEA framework and a set of activity matrices to generate standard production units against which the branch performances are evaluated
Cook and Zhu [113]	Canada	100	Sales staff, service staff, other staff	Service output, sales output	CRS	Identify and build efficient standards into the DEA analysis. The identified standard DMUs form an outer layer of the efficient frontier, compared to the DEA best practice frontier
Cook et al. [89]	Canada	20	Service staff, sales staff, support staff, other staff	No. of counter level deposits, no. of transfers between accounts, no. of retirement savings plan openings, no. of mortgage accounts opened	CRS	Derive an aggregate measure of branch performance that involving the sales and service functions, split the shared inputs for optimizing the aggregate efficiency score
Cook et al. [77]	Canada	1200	Full time equivalent staff, operating expenses	Service transactions, sales transactions	CRS, VRS	Two DEA-based benchmarking models are developed to study the change in branch performance, which moves from the old to the new structure. Examine whether the e-branches exhibit productivity gain
Coughlan et al. [114]	U.K.	232	Rent, no. of FTE staff, no. of tills, no. of ATMs, no. of interview rooms, no., of customers at start of five month period	No. of ATM cash transactions, no. of ATM non-cash transactions, no. of in-branch cash transactions, no. of in-branch non-cash transaction, sales, no. of customers at end of five month period	CRS	Illustrate the effect of including the customer as a resource in efficiency measurement
Das et al. [75]	India	222	No. of officers, no. of support staff, no. of clerks, physical capital	Value of deposit, value of credit, non-interest income	VRS	Measure labor-use efficiency of individual branches across four metropolitan regions in India. Introduce the concept of area/spatial efficiency for each region relative to the nation as a whole
Dekker and Post [37]	Netherland	314	Front-office personnel, facilitating personnel	Revenue	VRS	Propose a quasi-concave DEA model to relax the standard DEA assumptions of concavity for the production frontier
Deville [76]	France	1611	Human resources, operational resources, customer capital	Cash savings products, personal and business loans, access to services related to the management of account services, damage insurance products, financial savings products	VRS	Benchmark the operational performance of branches across 16 regional groups and 6 business environments
Drake and Howcroft [53]	U.K.	190	No. of interview rooms, no. of ATMs, floor area in square meters, management grades, clerical grades, stationery costs	Till transactions, lending products, deposit products, automated transfers, clearing items, ancillary business, insurance business	CRS, VRS	Investigate branch's productive efficiency. The measure of technical efficiency is dichotomized into scale efficiency and pure technical efficiency
Drake and Howcroft [54]	U.K.	190	No. of branch interview rooms, no. of ATMs, effective branch floor area, no. of management staff, no. of clerical staff, total branch stationery costs	Counter transactions, new and closed accounts relating to personal and business lending products, new and closed accounts relating to personal and business deposit products, direct debits and standing orders, clearing items, ancillary transactions, transactions relating to insurance products	CRS, VRS	Examine the relationship between branch size and efficiency. use tobit regression to identify the key determinants of DEA efficiency
Gaganis et al. [94]	Greece	458	Interest expenses, non-interest expenses, loan loss provisions	interest income, non-interest income	CRS, VRS	Examine the impact of market conditions on the efficiency and productivity scores. Examine the impact of risk-taking on the efficiency of the branches and examines the productivity

						growth of the branch network using the Malmquist TFP index
Gelade and Gilbert [115]	US	204	Branch staff	No. of new current accounts, no. of new loans, no. of new youth accounts, no. of new savings accounts, no. of new customers, customer satisfaction	VRS	Calculate the efficiencies of the branch offices in a retail banking network. Examine the relationship between the organizational climate as measured by employee's perceptions of operational and management efficiency
Giokas [50]	Greece	17	Labor, operating expenses, utilized branch space	Weighted number of transactions	CRS, VRS	Compare the operational efficiency of branches obtained from DEA and Log-linear Model Analysis. Examine the branch's scale efficiency
Giokas [51]	Greece	44	Model 1: personnel costs, running and other operating costs; Model 2: personnel costs, running and other operating costs; Model 3: interest costs, non-interest costs	Model 1: value of loan portfolio, value of deposits, non-interest income; Model 2: loan transactions, deposit transactions, remaining transactions; Model 3: interest income, non-interest income	CRS, VRS	Assess branch efficiencies in three different dimensions: managing the economic record, meeting customer transaction demands, and generating profits. examine the concordance of efficiency rating between DEA model and log-linear deterministic frontier model
Giokas [116]	Greece	171	Personnel costs, running costs, operating expenses	Value of deposits, value of loans, non-interest income	CRS, VRS	Examine the branch operating efficiency. Two semi-parametrical statistical tests and one additional Kolmogorov–Smirnov test are conducted to choose a appropriate DEA model for the analysis. Using regression analysis, examine the effects of size, market power, and location on operating efficiency
Golany and Storbeck [68]	U.S.	182	Teller operating hours, non-teller operating hours, retail square feet, mailing expense per customer, unemployment statistic	Loans, deposits, no. of accounts per customer, customer satisfaction	VRS	Evaluate the performances of bank branches with seeing the bank as a provider of financial services. Develop DEA-based target-setting models for examining marginal changes in the outputs or inputs profile of a branch
Haag and Jaska [117]	U.S.	14	Rent, personnel, supplies	Loan, new accounts, travelers checks sold +bonds sold+bonds redeemed, total deposits	VRS	Examine the correct interpretation of inefficiency scores and policy implications of the Additive DEA model. A region of stability is defined that identifies sufficient conditions for altering a technical inefficiency classification to that of technical efficiency
Hartman et al. [87]	Sweden	50	No. of staff, no. of computer terminals, square meters of premises	Deposits, loans, house mortgages	CRS, VRS	Analyze technical and allocative efficiency and organization change. Efficiency is examined by level of service. Trends in performance over two time periods are also analyzed
Howland and Rowse [118]	Canada	162	Model 1: non-sales staff, sales staff, branch size, city employment rate; Model 2: support and other staff, sales and service staff, % customers–branch, visa % of volumes	Model 1: loan volume, deposit volume, average no. of products/customer, customer loyalty; Model 2: non-wealthy business, wealthy business, growth in funds managed, customer loyalty	VRS	Evaluate the Canadian bank branch efficiencies using two DEA models: designed for American branches and a customized model for the Canadian branches. Analyze the outcome differences and explain the importance of variable selection
Jablonsky et al. [82]	Czech Republic	81	No. of employees, operating costs, floor space	No. of accounts, no. of transactions, value of savings	CRS	Propose a DEA model for forecasting branch future efficiency bounds based on interval input–output data set by bank management predictions
Kantor and Maital [101]	Mideast country	250	Model 1: labor costs, services, area for services; Model 2: labor costs, transactions, area for transactions	Model 1: no. of demand deposit accounts, weighted customer service transactions, queue replacing actions; Model 2: credit cards, weighted transactions, commissions, savings account activities	CRS	Integrate activity-based cost accounting system with DEA model for measuring the efficiencies of specific business activities in bank branches and facilitate precise measurement of waste and identify its causes
Lotfi et al. [46]	Iran	20	Payable interest, personnel, non-performing loans	Deposits, loans, received interest, fee	CRS	Incorporate decision maker's preference information into the process of DEA assessing efficiency using multi-objective linear programming
Lovell and Pastor [119]	Spain	545	No input	17 branch performance targets	VRS	Evaluate the bank branch operating performance and examine the performance of the target setting procedure employed by a

Table A1 (*continued*)

Author	Country/region	# of DMU	Input	Output	Model	Objectives
						large financial institution in Spain. Apply a "deletion of variables" technique in a DEA model to determine the optimal structure of targets
Manandhar and Tang [61]			Model 1: personnel-related expenses, supplies, office space, technology; Model 2: labor, supplies, office space, technology, the size of different accounts; Model 3: interest costs and non-interest costs	Model 1: aggregated measure of market focus, flexibility, internal organizational efficiency, empowerment; Model 2: no. of transactions, service quality; Model 3: interest revenue and non-interest revenue	VRS	Incorporate intangible aspects associated with resource inputs in the branches into internal service quality analysis. Benchmark branch performance along 3 dimensions: internal service quality, operating efficiency, and profitability dimensions using a modified DEA formulation
McEachern and Paradi [35]	7 countries	138	M1: interest, remuneration costs, other expense; M2: managers, tellers, personal banking staffs	M1: interest revenue, non-interest revenue, M2: teller transactions, new accounts opened	CRS	Conduct intra- and inter-country bank branch profitability and productivity assessment in seven national branch networks owned and operated by a multi-national financial services corporation. Provide advice in performance improvements both at the branch level and nationally
Meepadung et al. [78]	Thailand	165	Model 1: labor, non-interest expenses, interest expenses, internal customer service quality; Model 2: deposits, loans, IT-based transactions, cross-selling, external customer service quality	Model 1: deposits, loans, IT-based transactions, cross-selling; Model 2: interest income, non-interest income	CRS	Explore the impact of IT-based retail banking services on branch efficiency
Nash and Sterna-Karwat [80]	UK	75	NaN	Four products associated with housing loans	VRS	Measure branch's cross selling effectiveness. Introduce an additional output in the form of a count for non zero entries and a subsequent amendment of an additive DEA model to reduce the impact of the zeros on the analysis
Noulas et al. [5]	Greece	58	Labor expenses, other operating expenses	Deposit, loans, financial products	CRS	Examine the cost efficiency of branches in six major Greek cities. Investigate the effect of size on cost efficiency
Oral and Yolalan [48]	Turkey	20	Model 1: no. of personnel, the number of on-fine terminals, no. of commercial accounts, no. of saving accounts, no. of credit applications; Model 2: personnel expenses, administrative expenses, depreciation, interests paid on deposits	Model 1: time spent on general service transactions, time spent on credit transactions, time spent on deposit transactions, time spent on foreign exchange transactions; Model 2: interests earned on loans, non-interest income	CRS	Measure branch operating efficiencies. Investigate the relationship between service efficiency and profitability
Oral et al. [52]		44	Model 1: no. of personnel, no. of on-line terminals, no. of commercial accounts, no. of saving accounts, no. of checking accounts, no. of credit applications; Model 2: personnel expenses, administrative expenses, depreciation, non-interest expenses, interests paid on deposits	Model 1: time spent on all kinds of transactions; Model 2: interests earned on loans, non-interest income	CRS	Analyze branch operating productivities in a multi-market business environment and provide strategic implications in reallocating resources between the branches to achieve higher efficiencies
Paradi and Schaffnit [96]	Canada	90	Model 1: staff, information technology, rent, other non-interest expenses; Model 2: staff, information technology, rent, other non-interest expenses, non-accrual loans	Model 1: deposits, loans, operating services, account maintenance; Model 2: deposits, loans, operating services, deposit spread, loan spread	CRS, VRS	Evaluate branch performance with two production models customized for branch and senior management, respectively. Introduce new easy understanding methods to present graphical and numeric outcomes to managers
Paradi et al. [41]	Canada	156	M1: personnel, equipment, occupancy costs, other general expenses; Model 2: personnel, equipment, occupancy costs, other general expenses, deposits	Model 1: personnel deposits, mortgage loans, personal loans and secured lines of credit, small business loans; Model 2: personnel sales revenue, personal service revenue	CRS, VRS	Propose a new strategy to benchmark business units that operate under different cultural (business) environments. Two cultural indices are identified to represent a firm's unique operating environment
Paradi et al. [42]	Canada	816	M1: 9 types of branch FTE staffs; M2: cash balances, fixed assets/accruals, other liabilities, net non-performing loans, loans loss experience; Model 3: employee expense, occupancy/	M1: 9 types of transactions; M2: wealth management, homeowner mortgages, consumer lending, commercial loans, commercial deposits, consumer deposits; M3: revenues generated from: commissions, consumer deposits consumer	CRS, VRS	Propose a new two-stage DEA model to providing a comprehensive framework for three-dimensional performance measurement of a bank branch network: productivity, profitability, and intermediation. Integrate

			computer expense, loan losses, cross charges, other expenses, sundry; Model 4: NaN	lending, wealth management, home mortgages, commercial deposits, commercial loans; M4: DEA efficiencies obtained from M1, M2, and M3		multiple dimensional efficiency results to generate an overall efficiency score to allow a complete ranking. Examine economic effects of market size and geographical region and their effects on branch performance
Parkan [47]	Canada	35	Total authorized FTE, annual rent, quality of customer service space ranking, telephone/ stationary expenses, number of on-line terminals, marketing activity ranking	No. of transactions, Commercial account openings, Retail account openings, No. of loan applications, Customer service survey rating, No. of corrections	CRS	Identify branch operational inefficiencies. Discuss data related issues and implementation difficulties
Parkan [120]	Canada	36	Manager, assistant manager, post teller, customer service staff	Services directly generated revenue, services supporting the revenue-generation services	CRS	Propose an approach to compute inefficiency ratings for a set of branches to gage their relative operational competitiveness. The implement procedure allows for the calibration of the ratings to reflect managerial perceptions as to the significance of the various resource consuming and reward-generating activities involved
Parkan and Wu [106]	Hong Kong	1	Salaries, staff benefits, electronic data processing expenses, occupancy, temporary staff expenses, printing and stationary	LC (letter of credit) advice, LC confirmation, LC issuance, guarantee, acceptance, negotiation, net interest revenue	CRS	Investigate the direction of the performance trend and the impact of the incremental costs of hiring additional staff been on the performance. Compare the operational competitiveness rating analysis and DEA ratings and profit scores
Pastor et al. [102]	A European country	573	Personnel expense, other operating expense, deposit interest expense, delinquencies	Interest income, deposits, assets, customers, regular customers, high-income customers, return on assets, profitability	VRS	Evaluate the financial performance of branch offices in terms of their ability to conserve on the expenses they incur in building their customer bases and providing customer services
Porembski et al. [44]	Germany	140	No. of employees, office space	Private demand deposits, business demand deposits, Time deposits, Saving deposits, Credits, bearer securities, recourse guarantees, bonds, investment deposits, insurances, contributions to a building society	CRS, VRS	Visualize the reference and efficiency relations among the DMUs identified by DEA using Sammon's mapping
Portela and Thanassoulis [121]	Portugal	57	No. of staff, supply cost	Value of current accounts, value of other resources, value credit by bank, value of credit associates	VRS	Develop a DEA model adapting the geometric distance function to measure and decompose the profit efficiency
Portela and Thanassoulis [58]	Portugal	57	Model 1: no. of ETMs, rent, no. of clients not registered; Model 2: no. of staff, rent; Model 3: no. of staff, supply costs	Model 1: no. of new registrations for internet use, no. transactions in CATs, no. deposits in ETMs; Model 2: Δ no. of clients, Δ value current accounts, Δ value other resources, Δ value titles deposited, Δ value credit by bank, Δ value credit by associates, no. transactions; Model 3: value current accounts, value other resources, value credit over bank, value credit associates	VRS	Assess the branch performance in terms of transaction, operational and profit efficiency and investigate the relationships between them
Portela and Thanassoulis [122]	Portugal	57	No. of staff, rent	No. of transaction, Δ no. of clients, Δ value current accounts, Δ value other accounts, Δ value titles deposited, Δ value credit by bank, Δ value credit by associates	CRS	Develop an index and an indicator of productivity change that can be used with negative data
Schaffnit et al. [59]	Canada	291	Tellers, typing staff, accounting staff, supervision staff, credit staff	Counter transactions, counter sales, security transactions, deposit sales, personal loan sales, commercial loans, term accounts, personal loan accounts, commercial loan accounts	CRS, VRS	Analyze the efficiency of branch personnel and the impact of model choice on the results. Apply statistical tests to investigate the impact of external factors on personnel efficiency and the relationships between the efficiency and quality and profitability
Ševčovič et al. [123]	Slovakia	37	Credits granted, banking expenditures, salaries, operational expenditures	Credit profits, deposits, profit form banking operations	VRS	Assess the performance of branches with a normalized weighted additive model. Compare and analysis the DEA efficiencies obtained from the primal and dual models
Sherman and Gold [4]	U.S.	14	Labor, office space, supply costs	No. of transactions of four transaction types	CRS	Evaluate branch operating efficiency. Provide useful insights in locating inefficient branches

Table A1 (*continued*)

Author	Country/region	# of DMU	Input	Output	Model	Objectives
						by considering the mix of services provided and the resources used to provide these bank service
Sherman and Ladino [84]	US	33	Customer service staff, sales service staff, manager, expenses (excluding personnel and rent), office square feet	(1) Deposit, withdrawals, checks cashed, (2) bank checks, traveler checks, bonds (sold, redeemed, coupons), (3) night deposits, (4) loans, (5) new accounts	CRS	Improve branch productivity and profits while maintaining service quality
Sherman and Rupert [79]		217	Platform staff, manager, teller, operating expenses	Teller transactions, new accounts, safe deposit box visits, night deposits, ATMs serviced, no. of loan transactions	CRS	Analyze merger benefits based the comparison of the branch operating efficiencies in the merged bank and pre-merger banks
Sherman and Zhu [71]	U.S.	225	Platform FTEs, teller FTEs, management FTEs, other expenses	Deposits, bank checks, bond transactions, night deposits, safe deposit visits, new accounts, mortgage and consumer loans, ATMs	CCR	Improve benchmarking ability of a DEA model by incorporating quality factor
Soteriou and Stavrinides [69]	Mediterranean	26	Clerical personnel, managerial personnel, computer terminal, working space, no. of personal accounts, no. of savings account, no. of business accounts, no. of credit application accounts	Service quality	VRS	Develop a DEA model to incorporate the service quality as an output in order to provide suggestions towards internal customer service quality improvement
Soteriou and Stavrinides [70]	Mediterranean	26	Clerical personnel, managerial personnel, computer terminals, working space, no. of personal accounts, no. of savings accounts, no. of business accounts, no. of credit application accounts	Service quality	VRS	Develop a DEA model to incorporate service quality as an output to benchmark the branch internal customer service quality
Soteriou and Zenios [73]	Cyprus	39	Total branch cost	Foreign currency accounts, inter-branch transactions, current personal and savings accounts, credit application accounts, new credit application accounts initiated by each branch, credit application accounts renewals	CRS, VRS	Estimate the costs of bank products at the branch level by considering the utilization of resources
Sowlati and Paradi [104]	Canada	79	FTE sales, FTE support, FTE other	Loans, mortgages, registered retirement saving plans, letters of credit	VRS	Develop a DEA model that provides targets for empirically efficient units by defining a "practical frontier"
Stanton [81]	Canada	352	Capital, deposit, relationship costs, portfolio risk	Net income	CRS	Investigate the manager efficiencies in one of Canada's largest banks. Investigate the stability of the efficiencies and identify the underlying factors affecting the efficiency scores
Tsolas [124]	Greece	50	Personnel expenses, rental expenses, other operational expenses excluding interest expenses, depreciation	Income generated from selling Bank's assets, outcome of a predetermined function mapping the performance of the bank branch in giving loans to the clients, commissions, other non-interest income	VRS	Provide a two-stage DEA model for evaluating the overall performance of bank branches in terms of profitability efficiency and effectiveness
Valami [90]	Iran	24	Payable interest, personnel, non-performing loans	Deposits, loans granted, received interest, fee	CRS	Use the production technology concept for evaluating and comparing the performance of groups. Use the geometric mean of the output distance function from the efficient frontier corresponding to the group in the output space, and compare the technology change with respect to all DMUs
Vassiloglou and Giokas [49]	Greece	20	Person hours, monetary values of supplies, branch floor space, computer terminals	Four classes of transactions, with type A transactions being the 'easiest' and type D the 'most difficult'	CRS	Present a systematic application of DEA carried out in assessing branch efficiency
Wu et al. [38]	Canada	808	Personnel, equipment, occupancy, other expenses	Mortgage, non-term deposit, personal loans, small business loan, term deposit	CRS, VRS	Introduce the fuzzy logic formulation into DEA model to deal with the environmental variables so that the branch performance from different regions could be assessed
Wu et al. [45]	Canada	142	Personnel, other general expenses	Deposit, revenues, loans	CRS	Apply DEA model as a data filter to create a sub-sample training data set used for neural networks to evaluate the branch efficiency

Yang and Paradi [74]	Canada	70	Employment expenses, premise/IT expenses, other expenses	Loan, deposit, securities, gross revenue	CRS	Introduce a new DEA model to adjust cultural differences due to corporate management's policies. Benchmark performance of branches coming from three different Canadian banks
Yang et al. [125]	U.K.	14	Business reviews, contacts, registrations, key performance indicators, future value added	Customer service, commercial income	CRS	Develop a hybrid approach to incorporate the value judgments of both branch managers and head-office directors and to search for the most preferred solution along the efficient frontier for each bank branch
Yavas and Fisher [66]	U.S.	31	Retail deposits, small business deposits	No. of employees, lobby hours, no. of ATMs, safety deposit boxes, average wait	CRS	Evaluate and rank the operational performance of bank branches and identify the areas of deficiency
Zenios et al. [126]	Cyprus	145	Managerial personnel, clerical personnel, computer terminals, space, current accounts, savings accounts, foreign currency and commercial accounts, credit applications	Work (hours) produced by branch	CRS	Benchmark branches efficiency and identify the seasonal and environmental effects

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