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Invited Review

Assessing bank efficiency and performance with operational research and artificial intelligence techniques: A survey

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ABSTRACT

This paper presents a comprehensive review of 196 studies which employ operational research (O.R.) and artificial intelligence (A.I.) techniques in the assessment of bank performance. Several key issues in the literature are highlighted. The paper also points to a number of directions for future research. We first discuss numerous applications of data envelopment analysis which is the most widely applied O.R. technique in the field. Then we discuss applications of other techniques such as neural networks, support vector machines, and multicriteria decision aid that have also been used in recent years, in bank failure prediction studies and the assessment of bank creditworthiness and underperformance.

1. Introduction

Banks play a central role in the economy. They keep the savings of the public and finance the development of business and trade. Furthermore, numerous studies argue that the efficiency of financial intermediation affects economic growth while others indicate that bank insolvencies can result in systemic crises which have adverse consequences for the economy as a whole. Thus, the performance of banks has been an issue of major interest for various stakeholders such as regulators, customers, investors, and the general public. While bank performance has been traditionally evaluated on the basis of financial ratios, advances in operational research (O.R.) and artificial intelligence (A.I.) have resulted in a shift towards such quantitative techniques. Of course, this is not surprising, since O.R. has been extensively used in other applications in finance during the last half century (Board et al., 2003). This paper presents a comprehensive review of the use of O.R. and A.I. techniques in the assessment of bank efficiency and performance.

The rest of the paper is structured as follows. Section 2 positions the survey within the existing literature and discusses our framework. Section 3 discusses applications of data envelopment analysis (DEA) in the estimation of bank efficiency and productivity growth. Section 4 presents applications of other O.R. and A.I. techniques in the prediction of bank failure and the assessment of bank creditworthiness and underperformance. Section 5 summarizes our conclusions.

2. Aims and framework

There are several interesting reviews that are related to our survey. For example, Cook and Seiford (2009) review the methodological developments of DEA over the last thirty years. However, they do not discuss applications of DEA. Zhou et al. (2008) provide a recent survey of DEA applications but they focus on energy and environmental studies. Dimitras et al. (1996) discuss applications of various techniques in the prediction of business failures but they focus on industrial firms. Ravi et al. (2008) discuss applications of statistical and A.I. techniques in bankruptcy prediction.[1] Smith and Gupta (2000) provide a discussion of the application of neural networks in business problems, while Board et al. (2003) survey O.R. applications in financial markets. Thus, the above surveys are either quite general or they do not focus on applications in banking.

Berger and Humphrey (1997) review studies that examine the efficiency of financial institutions. However, their coverage is limited to efficient frontier techniques (e.g. DEA, stochastic frontier analysis). Furthermore, the survey is now more than 10 years old and since that time, numerous papers have been published. Berger

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[1] The applications discussed in Ravi et al. (2008) were published until 2005, and although a few of them focus on the banking sector, most of the studies deal with non-financial firms.

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(2007) discusses more recent applications of frontier techniques but his survey focuses only on studies that provide international comparisons of bank efficiency.

We differentiate our review from the above surveys by discussing applications of O.R. and A.I. techniques over the period 1998–early 2009 while focusing on bank performance. We searched for papers in Scopus, which is considered to be one of the largest abstract and citation databases. We consider only journal articles and we do not include working papers, monographs, dissertations, or other publication outcomes. Furthermore, our search is limited to articles written in English. We use a combination of various keywords such as "bank efficiency", "bank and data envelopment analysis", "bank performance", "bank and neural networks", "bank and artificial intelligence", "bank and operational (or operations) research". Additional studies were identified from cross-referencing and were manually collected.

We reviewed a total of 196 studies. DEA is by far the most commonly used O.R./A.I. technique in assessing bank performance and we identified 151 studies that use DEA-like techniques to estimate various measures of bank efficiency and productivity growth, and 30 studies that provide similar estimates at the branch level.[2] We also identified 15 studies that use classification techniques such as neural networks, support vector machines, multicriteria decision aid, decision trees, nearest neighbours to predict bank failure or assess bank creditworthiness, and bank underperformance. These studies were published in a total of 73 journals, however, around 58% of them appeared in just 12 journals. The most frequent sources of publication are the *European Journal of Operational Research* (19) and the *Journal of Banking and Finance* (15), followed by *Applied Financial Economics* (13), *Managerial Finance* (11), *Applied Economics* (9), *Expert Systems with Applications* (9), the *Journal of Productivity Analysis* (9), and the *Journal of Economics and Business* (8).[3]

3. DEA and bank efficiency

DEA is a mathematical programming technique for the development of production frontiers and the measurement of efficiency relative to these frontiers. Each bank is assigned an efficiency score between 0 and 1, with higher scores indicating a more efficient bank, relatively to other banks in the sample.

One of the well-known advantages of DEA is that it works relatively well with small samples. Other advantages of DEA are that it does not require any assumptions to be made about the distribution of inefficiency and it does not require a particular functional form on the data in determining the most efficient banks. However, DEA is also subject to few limitations. Two of the best-known shortcomings are that DEA assumes data to be free of measurement error, and that it is sensitive to outliers. Coelli et al. (2005) also point out that: (i) having few observations and many inputs and/or outputs will result in many firms appearing on the DEA frontier; (ii) treating inputs/outputs as homogenous commodities when they are heterogeneous may bias the results; (iii) not accounting for differences in the environment may give misleading results; (iv) standard DEA does not control for multi-period optimisation or risk managerial decision making.

Our survey shows that recent DEA studies have examined almost all of the banking sectors around the world. A few recent studies provide cross-country evidence. Most of them examine banks from the large EU banking sectors (Casu and Molyneux, 2003; Beccalli et al., 2006). Lozano-Vivas et al. (2002) examine 10 EU countries, Bergendahl (1998) focuses on Nordic countries, while Pasiouras (2008a) and Tanna (2009) examine international datasets.

3.1. Methodological issues

3.1.1. Efficiency measures

Most of the studies focus on the technical efficiency of banks (e.g. Lozano-Vivas et al., 2002; Drake et al., 2006; Pasiouras, 2008a,b). This efficiency measure indicates whether a bank uses the minimum quantity of inputs to produce a given quantity of outputs or maximizes the output quantity given a certain quantity of inputs.

However, when price data for the inputs and/or outputs are available one can also estimate cost and/or profit efficiency measures.[4] Cost efficiency is the product of technical efficiency and allocative efficiency. The latter refers to the ability of a bank to use the optimum mix of inputs given their respective prices. Consequently, cost efficiency shows the ability of a bank to provide services without wasting resources as a result of technical or allocative inefficiency. As can be seen in Table 2 of the Supplementary material (Appendix A), around 35 studies present measures of DEA cost efficiency (e.g. Tortosa-Ausina, 2002a; Isik and Hassan, 2002, 2003a).

Pastor and Serrano (2006) propose the decomposition of cost inefficiency into composition inefficiency and intra-specialisation inefficiency. The first component indicates the part of inefficiency due to the composition of specialisations of the banks in each banking sector. The second component reveals the inefficient use of resources within each of the specialisation selected. Prior (2003) also deviates from the above studies by calculating measures of short and long-run cost inefficiency as well as capacity inefficiency for Spanish banks. The first refers to the case that a subset of inputs are fixed and impossible to modify in the short-run. Long-run inefficiency estimates are obtained under the assumption that inputs are variable and under the control of the company. Finally, capacity inefficiency, obtained by the ratio of long-run to short-run inefficiency, refers to excess in costs as a result of inappropriate level in fixed inputs. Similar concepts along with an application in the Indian banking sector are discussed in Sahoo and Tone (2009).

Estimations of profit efficiency with DEA are rather limited in the literature. One potential reason is the difficulty in collecting reliable and transparent information for output prices. Furthermore, the decomposition of profit efficiency into technical and allocative efficiency is not straightforward (Coelli et al., 2005). Fare et al. (2004) propose the solution of two sets of linear programmes. In the first, a profit maximizing DEA is solved to measure profit efficiency. In the second DEA problem, technical efficiency is measured on the basis of a directional distance function that allows the simultaneous adjustment of inputs and outputs. Kirkwood and Nahm (2006) also estimate profit efficiency, although they use input prices only. Therefore, in a sense they calculate a measure of efficiency that is similar to Berger and Mester (1997) "*alternative profit*" efficiency which is commonly used in the stochastic frontier analysis literature. The studies of Maudos and Pastor (2003) and

[2] Our survey focuses on studies that examine banking institutions as a whole; however, we also discuss studies on branch efficiency in Section 3.2.7 as one could argue that the efficiency of individual branches can influence the performance of banks as a whole.

[3] In the sections that follow, we discuss various issues surrounding these studies, while additional information is available in the Supplementary material (Appendix A).

[4] One can also estimate revenue efficiency which is similar to profit efficiency. In both cases, both inputs and output prices are required. The difference is that in the former measure the aim is to maximize revenues rather than profits (i.e. revenues minus costs). We are no aware of DEA studies focusing on revenue efficiency so we do not discuss this issue further. Readers interesting in revenue efficiency could see Coelli et al. (2005) for further details.