European Journal of Operational Research 255 (2016) 411–421

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Production, Manufacturing and Logistics

A parallel production frontiers approach for intertemporal efficiency analysis: The case of Taiwanese commercial banks

Chiang Kao[a],*, Shiang-Tai Liu[b]

[a] Department of Industrial and Information Management, National Cheng Kung University, Tainan, Taiwan, ROC
[b] Graduate School of Business and Management, Vanung University, Chung-Li, Taiwan, ROC

ARTICLE INFO

Article history:
Received 9 March 2015
Accepted 27 April 2016
Available online 16 May 2016

Keywords:
Data envelopment analysis
Malmquist productivity index
Production frontier
Efficiency change
Technical change

ABSTRACT

A comparison of the efficiency of a production unit at one period with those of other units at another period is challenging, because the bases for calculating efficiency are usually different. The Malmquist productivity index (MPI) is an effective measure that can overcome this difficulty. However, the existing measures of this index have various weaknesses with regard to feasibility, circularity, decomposability, and consistency. This paper thus develops a model to construct parallel production frontiers for the units at different periods to measure the MPI. This model is always feasible, the calculated MPI has the property of circularity, it can be decomposed into the product of efficiency change and technical change, and the results are consistent. An application of this model to Taiwanese commercial banks for the period 2008–2013 confirms these merits. The results also indicate that in general the MPIs of these banks increased from 2008 to 2013, and this was attributed to improvements in technology. Since the efficiencies measured from the parallel model are comparable among different units and different periods, they can be used for intertemporal analysis to identify the banks with unsatisfactory performance in different periods.

1. Introduction

As global competition becomes keener, firms in general are devoting more efforts to improving their performance in order to survive. To investigate whether the performance of a production unit, or more generally a decision making unit (DMU), has improved or not, Bitran and Chang (1984) pointed out that it is necessary to compare the focal DMU with itself at different time points, as well as with other DMUs at the same time point, in order to obtain valid productivity measures. A measure based on this concept is the Malmquist productivity index (MPI), developed by Caves, Christensen, and Diewert (1982a, 1982b) (hereafter referred to as CCD MPI), which is the ratio of the efficiency indexes of a DMU at two periods calculated based on the production frontier of one period. If this ratio is greater than unity, then the performance has improved, and if not, it has declined.

Clearly, using different periods as the base period to calculate the efficiency index may produce different or even contradictory results (see Kao (2010) for an example of this), that is, one base period may show an improvement, while another shows a decline. Färe, Grosskopf, Norris, and Zhang (1994) suggested using the geometric mean of the MPIs calculated from two different base periods as the final MPI (hereafter referred to as FGNZ MPI), and were able to decompose it into the product of efficiency change and technical change, where the efficiency change is the ratio of the efficiencies of the two periods measured independently based on their respective production frontiers, and the technical change is basically the relative distance between the production frontiers of the two periods. This MPI has been widely applied to measure changes in performance of a DMU over time, and the works of Brennan, Haelemans, and Ruggiero (2014), Chou and Shao (2014), Chowdhury, Zelenyuk, Laporte, and Wodchis (2014), and Podinovski, Ismail, Bouzdine-Chameeva, and Zhang (2014) are some recent applications of this approach.

One weakness of the FGNZ MPI (and also the CCD MPI), as pointed out by Aparicio, Pastor, and Zofio (2013), is that infeasibility (or unboundedness in the dual formulation) may occur when using the production frontier of one period to calculate the efficiency index of another under the assumption of variable returns to scale. Conceptually, measuring the efficiency index of a DMU at one period based on the production frontier of another is similar to the case of calculating the super efficiency of an efficient DMU proposed by Andersen and Petersen (1993), in that infeasibility is a well known phenomenon (Seiford & Zhu, 1999). Moreover, the property of circularity that the CCD MPI has is not retained. Pastor and Lovell (2005, 2007) thus proposed a global MPI, which uses

---

* Corresponding author. Tel.: +886 6 2753396.
E-mail addresses: ckao@mail.ncku.edu.tw (C. Kao), stliu@vnu.edu.tw (S.-T. Liu).

http://dx.doi.org/10.1016/j.ejor.2016.04.047
0377-2217/

the data of every DMU in all periods to construct a global production frontier to measure the relative efficiencies of each DMU at different periods, and the ratio of the efficiencies of a DMU at two periods as the MPI. The corresponding model is always feasible, and the MPI has the property of circularity. Kao and Liu (2014) and Kao and Hwang (2014) used this index to measure the changes in performance of the commercial banks and the non-life insurance companies in Taiwan, respectively. An important assumption of the global MPI is that the production technology remains the same for all periods, so that a global production frontier can be constructed. This assumption prohibits each period to have its own production frontier. The global MPI cannot thus be decomposed, in contrast to what is possible with the FGNZ MPI.

A similar idea is the metafrontier approach, where a metafrontier is constructed upon all period frontiers (Battese & Rao, 2002, Battese, Rao, & O'Donnell, 2004, O'Donnell, Rao, & Battese, 2008). The efficiency of a DMU can be measured based on the period frontier and metafrontier. How close a period frontier is to the metafrontier can then be examined. Oh and Lee (2010) applied this approach with a metafrontier Malmquist index to calculate the productivity growth of fifty-eight countries in the world, and Choi, Oh, and Zhang (2015) used this approach with a metafrontier Malmquist–Luenberger index to measure the environmentally sensitive productivity growth of thirty provinces in China. Since the period frontiers of this approach may still intersect with each other, one may obtain inconsistent MPIs, as would the Färe et al. (1994) approach.

The MPI is an aggregate measure of the change in performance due to deviations from and shifts in the production frontiers. A deviation from the frontier reflects how efficiently a DMU transforms inputs into outputs, which can usually be controlled by the DMU. In contrast, shifts in the frontier are caused by outside factors, such as new policies, technological advances, wars, financial crisis, or energy crisis, which cannot usually be controlled by the DMU. Färe et al. (1994) termed the former as efficiency changes and the latter as technical changes.

The production frontier of each period is constructed independently when calculating the FGNZ MPI. In this case, the technical change of a DMU, as measured from the frontier of one period, may be quite different from that measured from the frontier of another period. When two frontier facets intersect, the technical changes measured from these may even contradict to each other. The idea of Färe et al. (1994) for taking the geometric average of them certainly alleviates the contradictory effect; however, its conclusion is still susceptible. For cases of more than two periods, where this phenomenon of intersecting becomes more complicated, the technical changes that are obtained are even more difficult to interpret.

To address these problems, this paper proposes the idea of constructing parallel frontier facets for the same DMU at different periods, taking the general trend of the observations at all periods into consideration. The parallel frontiers provide consistent measures of technical changes for all DMUs at different periods. More importantly, the MPIs and technical changes obtained in this way have the property of circularity. By eliminating the effects of technical change from the MPI, the results reflect only those of the efficiency change between two periods. This idea is applied to measure the efficiency and technical changes of commercial banks in Taiwan.

Taiwan is a relatively small island, with an area of thirty-six thousand square kilometers. However, the prosperous economic development in the past forty years has accumulated its foreign reserves to an amount of 425.3 billion US dollars, as of December 2015, which is ranked fifth in the world. To handle the related financial businesses, many banks have been established, which cause competitions. Banks in Taiwan must therefore evaluate their performance relative to the others to find their weaknesses to make improvement, so that they can survive in this competitive environment. Several studies in the literature have investigated the performance of Taiwanese banks. For example, Kao and Liu (2004) predicted the performance of 24 commercial banks based on their financial forecasts. Lin, Hsu, and Hsiao (2007) measured the relative efficiency of management and variations in this among 37 banks for the period 2002–2003. Chiu, Jan, and Shen (2008) examined whether a bank's technical efficiency changed significantly when capital adequacy was specified for 46 banks over the period 2000–2002. Hsiao, Chang, Cianci, and Huang (2010) investigated the effects of the First Financial Restructuring, which occurred in 2001, on the operating efficiency of 40 commercial banks over a six-year period (2000–2005). Kao and Liu (2014) measured the performance change between two three-year periods, 2005–2007 and 2008–2010. All of these studies used the conventional way of constructing an independent frontier for each period to measure efficiency, with the results relying heavily on the production frontier of the base period. Moreover, the effects of the efficiency change are confounded with those of the technical change. By applying the idea presented in the current study to construct parallel frontier facets for all periods, the technical change can be measured more accurately, and the efficiency and technical changes are properly differentiated. The results can thus help identify the causes of overall performance changes between two periods.

In the next section, we will use an example to illustrate the idea of using parallel frontier facets to measure technical changes under variable returns to scale (VRS). Then, in Section 3, we propose a parallel model for general cases, and show the decomposition of the MPI into the product of efficiency and technical changes. The property of circularity possessed by the MPI is discussed, as is the technical change calculated from the parallel model. A special case of variable returns to scale is constant returns to scale (CRS), where the intercept parameter is equal to zero, and Section 4 discusses this special case. After that, the efficiency and technical changes of twenty-two commercial banks in Taiwan in the period 2008–2013 are calculated in Section 5, using the parallel model developed under VRS. Finally, some conclusions are presented in Section 6.

2. The basic idea

The relative efficiency of a DMU is comparable to that of another one only if they are calculated from the data of the same period. The Malmquist productivity index (MPI) is generally used to compare the performance of a DMU at two different periods, and this is the ratio of the efficiency indexes of a DMU at two periods calculated based on the production frontier of the same period. The efficiency index can be effectively measured by the data envelopment analysis (DEA) technique.

Let $X_{ij}^{(t)}$ and $Y_{rj}^{(t)}$ denote the ith input, $i = 1,\ldots, m$, and rth output, $r = 1,\ldots, s$, respectively, of the jth DMU, $j = 1,\ldots, n$, at period t, $t = 1,\ldots, p$. The relative efficiency of DMU k at period t under VRS can be measured via the following BCC model (Banker, Charnes, & Cooper, 1984):

$$\begin{aligned} E_k^{(t)} = \max.\ & \frac{\sum_{r=1}^{s} u_r Y_{rk}^{(t)}}{v_0 + \sum_{i=1}^{m} v_i X_{ik}^{(t)}} \\ \text{s.t.}\ & \sum_{r=1}^{s} u_r Y_{rj}^{(t)} - \left(v_0 + \sum_{i=1}^{m} v_i X_{ij}^{(t)} \right) \le 0, \quad j = 1,\ldots,n \\ & u_r, v_i \ge 0, r = 1,\ldots,s,\ i = 1,\ldots,m \\ & v_0 \text{ unrestricted in sign.} \end{aligned} \tag{1}$$

A lower bound ε can be imposed for the multipliers u_r and v_i to avoid ignoring unfavorable factors in the evaluation (Charnes & Cooper, 1984). The objective function is a fractional, which can be