Estimating Two-Stage Network Technology Inefficiency: An Application to Cooperative Shinkin Banks in Japan

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ABSTRACT

The authors model the performance of DMUs (decision-making units) using the directional distance function within a two-stage framework. In the first stage of production, DMUs use inputs to produce an intermediate output. In stage 2, the intermediate output is used to produce final outputs. In contrast to DEA (data envelopment analysis) models, the two-stage directional model accounts for a network production structure and allows non-radial scaling of outputs and inputs. An empirical application of the method is provided for Japanese credit cooperative Shinkin banks. These banks use labor, physical capital, equity capital in a first stage to produce deposits, and then use the deposits to produce loans, securities investments, and other interest bearing assets in a second stage. The authors find evidence of greater inefficiency in the first stage of production than in the second stage of production. In addition, the findings indicate that models that ignore a network structure and measure performance using a black-box DEA model miss about 50% of total bank inefficiency when measured by the network model.

Keywords: DEA, Directional Technology Distance Function, Network Technology Inefficiency, Shinkin Bank (Credit Association), Two-Stage System

INTRODUCTION

Traditionally, DEA (data envelopment analysis) has been used to measure the performance of DMUs (decision making units) within a black-box production framework. The black-box framework measures performance for all inputs and outputs produced by a DMU, but ignores any synergies between various stages of production or divisions within a firm. Farrell (1957) efficiency measures are frequently used in the black-box approach and such measures estimate the potential for a DMU to expand outputs proportionally given inputs, or to contract inputs proportionally given outputs. Such efficiency measures will be biased to the extent that production has a network structure, with production divided into stages or within divisions, where the outputs of one stage of production are inputs to another stage. With a network structure, one might expect the manager of the

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first stage to try and maximize the production of the output, while the goal of the manager of the second sub-process is to minimize the use of the input that is derived from the first stage. To incorporate the inner workings of the black box into performance measurement, Färe and Grosskopf (2000) extended Shephard and Färe’s (1980) production framework into a network DEA model. As a special case of the network DEA model Wang, Gopal, and Zionts (1997) and Seiford and Zhu (1999) analyzed the efficiency of decision-making units engaged in two-stage production. Related to the network structure is the merger and acquisition index proposed by Färe, Fukuyama, and Weber (2010) which measured the potential output gains that could be realized via an optimal re-combination of decision-making units.

For industries where decision-making units are vertically integrated, with the outputs of one stage becoming inputs for another stage, a proper accounting of the network production process is important for evaluating the true performance of decision-making units. In agriculture, a network production process occurs when some grain produced in one year is used as seed in a subsequent year, or is used as feed for livestock. In addition, parts of a livestock herd are often produced as both final output and used as an input as breeding stock for future livestock generation or as beasts of burden in planting seeds or transporting grain to market. In education, the value added to students’ knowledge in one grade becomes part of the human capital stock used by teachers in a higher grade. In transportation, sea cargo is often transported further inland by rail or truck. If the rail sector of one country is evaluated relative to another country without accounting for the efficiency with which shipping containers can be offloaded in both countries, then a misleading picture of relative rail performance might appear. In banking, branches of a given bank are often used to collect deposits which are transformed into a portfolio of loans and other investments for the main bank. Such examples suggest that accounting for network production has important consequences for performance evaluation.

In a recent paper, Kao and Hwang (2008) extended network Farrell input efficiency measures and showed that whole-system efficiency can be decomposed into the product of sub-process efficiencies, although the decomposition is not necessarily unique. Taking this fact into account, Liang, Cook, and Zhu (2008) developed two approaches to analyze network efficiency: a game-theoretic non-cooperative approach and a centralized approach.

In the non-cooperative approach, efficiency is first measured for the stage where the managers are presumed to be the leaders and then second, efficiency is measured for the stage where the managers are the followers given the efficiency of the leaders. Network efficiency equals the product or sum of leader stage and follower stage efficiency. In contrast, the centralized approach maximizes the efficiencies of the two stages simultaneously by treating the shadow price multipliers of intermediate outputs/inputs at stages 1 and 2 as equivalent.

Assuming a single intermediate output and using Farrell efficiency measures, the non-cooperative and centralized approaches yield a unique multiplicative decomposition of whole-system efficiency. However, when there are multiple intermediate products, the two approaches can yield multiple decompositions of whole-system efficiency. Because of this possibility, Cook, Liang, and Zhu (2009) suggested testing for uniqueness of whole system efficiency using Farrell efficiency measures.

A shortcoming of the Farrell efficiency measure is that outputs or inputs are scaled proportionally to the production frontier, whereas a non-radial expansion of outputs or a non-radial contraction of inputs might be more appropriate. For instance, if a DMU is regulated to producing a maximum of one particular output or regulated to use no less of one particular input, a non-radial efficiency measure might provide a better estimate of DMU performance. The network models of Liang, Cook, and Zhu (2008) and Seiford and Zhu (1999) are based on Farrell radial measures of efficiency. To generalize
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