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Measuring the change in R&D efficiency of the Japanese pharmaceutical industry

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ABSTRACT

This paper presents a data envelopment analysis (DEA)/Malmquist index methodology for measuring the change in R&D efficiency at both firm and industry levels. Letting each of ten firms in each year be a separate decision-making unit, and employing one input and three outputs in a DEA case of R&D activity input–output lag, we measure "total factor R&D efficiency" change of Japanese pharmaceutical firms for decade 1983–1992 as defined by the period of R&D input. Decomposing Malmquist index into catch-up and frontier shift components and using "cumulative indices" proposed in this study, we evaluate R&D efficiency change for each firm and empirically show that R&D efficiency of Japanese pharmaceutical industry has almost monotonically gotten worse throughout the study decade.

1. Introduction

This paper measures R&D efficiency of Japanese pharmaceutical firms and examines how R&D efficiency at industry level has changed over time. R&D in firms, which can be considered as a stage prior to production, would be as important as production. But we have not quantitatively analyzed R&D efficiency so much as productivity. The lack of how to measure R&D efficiency would be a main reason. In considering R&D activity input and output, we cannot immediately specify what to be as the output, compared with R&D investment as the input. Geisler (1995) and Brown and Svenson (1998) list published articles, patents, new products, etc. as the output. That is, we cannot help considering multiple outputs of R&D. This multiplicity of output prevents from analyzing R&D efficiency by means of ordinary production function, i.e., parametric, approach.

Thus it is not easy to measure R&D efficiency, so that we have seldom observed its chronological transition at industry level. Has it gradually gotten better as incorporating some innovations into process as productivity could be expected? For the recent Japanese industry, it might not, or might have even worsened (Sakakibara and Tsujimoto, 2003). For also pharmaceutical industry in the world, it is said that R&D efficiency is recently in decline (Tollman et al., 2004). After all, the recent change in R&D efficiency has yet been elusive. Taking up Japanese pharmaceutical industry, we verify whether R&D efficiency has gotten better or worse for the study period.

In order to analyze R&D efficiency, we employ *data envelopment analysis* (*DEA*) (e.g., Cooper et al., 2000). DEA is a non-parametric method that can measure the relative efficiency, i.e., *DEA efficiency*, of objects called *decision-making units* (*DMUs*) with multiple *inputs* and multiple *outputs*. Although DEA could be applied to various fields other than the standard efficiency analysis (e.g., Hashimoto and Ishikawa, 1993; Hashimoto, 1996), its characteristic that is able to deal with multiple outputs has enabled measuring efficiencies of a novelty of DMU sets even in the standard analysis. For example, Nasierowski and Arcelus

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(2003) recently measure the efficiency of 45 national innovation systems with two inputs and three outputs. However, we can find no DEA analyses of firms' R&D efficiency except for Honjo and Haneda (1998). They try to analyze R&D efficiency of fourteen Japanese pharmaceutical firms with one input and two outputs for period 1977–1991. Refining their analyses, we also preparatorily do DEA analyses using panel data from ten pharmaceutical firms for the study period. But we should note that ordinary DEA cannot analyze as taking *DEA efficiency frontier* shifting over time into consideration.

Then, we introduce *DEA/Malmquist index* analysis (e.g., Färe et al., 1994; Thanassoulis, 2001) to examine time series change in R&D efficiency at industry level. The Malmquist index can measure the ratio of DEA efficiencies in two different time periods with shifting DEA efficiency frontiers. Although we have some DEA/Malmquist index applications (Färe et al., 1994; Coelli et al., 1998; González and Gasćon, 2004; etc.), they are all to productivity change. The Malmquist index can be decomposed into two components: "catch-up" and "frontier shift." While the former measures how much closer to the frontier a DMU, i.e., a firm, moves, the latter does movement of the frontier. Since the frontier is composed of "DEA efficient" DMUs among all firms in a time period, the frontier shift means change at industry level. Using this frontier shift, we devise to quite obviously display R&D efficiency change of Japanese pharmaceutical industry throughout the study period.

2. Input and output to measure R&D efficiency

To DEA-analyze R&D efficiency of Japanese pharmaceutical firms, we must select DEA input and output. DEA relatively evaluates how efficiently DMUs convert multiple inputs into multiple outputs. That is, any DMU producing more outputs with fewer inputs is judged relatively efficient. As the input, we straightforward employ *R&D expenditure* (billion yen a year). Rather, we measure the efficiency of activities appropriated as the R&D expenditure. This indicator also involves the concept of number of researchers as an R&D input.

For the output, we propose the following three dimensions: We first list *patents* (number of patent applications publicly published in a year) as a proxy of invention, i.e., an indicator directly reflecting level of R&D outcomes. Next, we consider the other phases of outcomes. R&D activities in firms can be divided into two: one aiming at "product innovation" and the other aiming at "process innovation." The former contributes sales increase through product discrimination, and the latter does profit increase through cost reduction (Odagiri, 1987). Considering two proxies of the product and process innovations, we employ *pharmaceutical sales* (10 billion yen a year) and *operating profit* (billion yen a year) as two additional outputs. Since the sales and profit can vary for the reasons (in-licensed new-products, marketing efforts, price regulations, etc.) other than R&D expenditure, the input, these might not be fittest as the output. But we use them because we could not find any better proxies of product and process innovations, and because the key contribution of the study is to evolve a methodology to measure R&D efficiency change with multiplicity of the R&D output.

For these one input (R&D expenditure) and three outputs (patents, pharmaceutical sales, operating profit), we initially provide four data panels as follows: Each panel consists of 10 firms $\times$ 20 years. That is, the sample period is latest 1982–2001 and the 10 pharmaceutical firms are Takeda, Sankyo, Yamanouchi, Daiichi, Eisai, Shionogi, Fujisawa, Chugai, Tanabe and Yoshitomi. They are all big enterprises driving R&D and seem homogeneous as professional-medicine makers. Although we took the biggest thirteen pharmaceutical firms of Japan into consideration at the beginning, Kyowa-Hakko and Meiji-Seika were excluded because each firm's medicine sales did not reach to fifty percent of each whole sales. We also excluded Taisho because of its characteristic as a popular-medicine maker peculiar vs other firms. We collect annual data to the one input and three outputs, for the ten firms in the period 1982–2001, from *Data Book* (Tokyo: Japan Pharmaceutical Manufacturers Association) and *NEEDS Database* (Tokyo: Nihon Keizai Shimbun, Inc.). The four indicators except for patents are all deflated to the 2001 value.

In DEA-analyzing R&D efficiency in a year, it is not appropriate to apply input and output data of the same year. We should consider that variations in input would cause observed variations in output of some years later. How many years would be the time lag between R&D expending and realization of its outcomes? Science and Technology Agency, Japan (1985) states that average years of the lag would be 8.08 for the Japanese pharmaceutical industry. Odagiri and Murakami (1992) estimate the lag 6–8 years. Based on these reports, we here employ 8 years, i.e., we use input data of a year together with output data of 8 years later. However, this input–output correspondence at intervals of 8 years would not so strict that we first compute 3 years moving averages being the middle year's values for the four indicators in the period 1982–2001, and obtain data panels for 1983–2000 (i.e., data of 1982 and 2001 are dropped). Merging the moving-averaged input data for 1983–1992 in the moving-averaged output data for 1991–2000, we reconstruct four data panels consisting of ten firms to analyze R&D efficiency for 10 years. Since the year of R&D efficiency should be defined as the year of R&D activity input in input–output lag cases, we consequently measure the efficiency in R&D activities of *decade 1983–1992* in spite of using the recent R&D data. For the time lag, we also tried 7 and 9 years lag cases. It should be noted that results of both cases had same tendency as the 8 years lag case this study adopts.

3. Preliminary DEA analyses of R&D efficiency

We preliminarily DEA-analyze R&D efficiency of Japanese pharmaceutical firms using panel data for the study decade 1983–1992 as defined by the period of R&D activity input. DEA model we employ is the *CCR* (Charnes et al., 1978) assuming the *constant returns-to-scale*. The CCR model in its *weak efficiency*, *input-oriented* and *envelopment* form to measure DEA efficiency (R&D efficiency) of target DMU j_0, $g_{j_0}(0 \leq g_{j_0} \leq 1)$, is formulated as the following lin-