論文の内容の要旨

論文題目 Measures of research and development productivity for the pharmaceutical industry using the two-stage data envelopment method

（2 段階データ包絡法による、製薬産業の研究開発生産性の測定）

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Analysis of research and development (R&D) productivity of the pharmaceutical industry has increased. A pharmaceutical company needs to improve R&D productivity to sustain earnings and some papers argue the decline of R&D productivity is a cause of mergers and acquisitions (M&A). However, a conventional method for measuring R&D productivity on an individual basis is based on R&D efficiency, i.e., a ratio of R&D spending to number of successful new molecular entities (NMEs), and there are limitations to examining relationships between R&D productivity and industry consolidation. Few methods incorporate the nature of the pharmaceutical industry, including differences in therapeutic category risk profiles, and measure R&D productivity on an individual company basis. The goal of this dissertation is to develop a novel method to measure R&D productivity of an individual pharmaceutical company incorporating industry characteristics. Based on these outcomes, relationships between R&D productivity and industry consolidation and between R&D productivity and therapeutic categories are investigated.

Out of 24 publicly listed Japanese companies since 1980, 15 are selected using one input variable (actual R&D spending) and three output variables (accumulated number of weighted NMEs, sales, and operating profit). The weight is assigned based on development stage using an interview form

regarding R&D spending: 50% for in-licensed NME and 20% for co-development NME. Annual reports from 1970 to 1997 are used for financial information and 1997 is the endpoint because it marks the end of the non-M&A period.

Out of 50 global pharmaceutical companies, 21 are selected and three variables are employed: R&D spending, number of NMEs, and aggregated net present value (NPV). R&D spending is obtained from annual reports from 2002 to 2012. We include 604 NMEs in the data set that were engaged in a Phase III study initiated between 2002 and 2007 or between 2008 and 2012 (using annual reports). NPVs of 21 global pharmaceutical companies from Pharmapipeline® were obtained from Barclays Capital. The data collection endpoint is 2007 because it marks a period just before several large M&A transactions.

To visualize company R&D productivity among industry peers, a relative ranking approach is used to eliminate an impact on size effect. This approach is based on data envelopment analysis (DEA) since DEA is based on distance from the efficiency frontier constructed from optimal companies. The Malmquist index is employed to identify historical R&D productivity changes in Japanese companies from 1980 to 1997.

We deconstruct R&D productivity into two components: cost efficiency (number of NMEs divided by R&D spending) and product value effectiveness (product value divided by number of NMEs). Based on these scores, a benchmark is constructed that employs two-stage DEA. An advantage of using two-stage DEA is the ability to measure overall R&D productivity. The cost efficiency index (number of optimized NMEs divided by R&D spending) and product value effectiveness index (product value divided by number of optimized NMEs) for each company are measured. The

optimized number of NMEs minimizes the difference between two indices to estimate overall optimal R&D productivity. A R&D productivity map is constructed using the cost efficiency index (x-axis of the map) and product value effectiveness (y-axis).

Results using the Malmquist index indicate that the R&D productivity of the 15 Japanese companies declined and that there is dispersion of R&D productivity deterioration. RDP map results illustrate that companies with optimal cost efficiency ($p < 0.05$) merged with companies with the least-optimal product value effectiveness ($p < 0.10$). The four largest therapeutic franchises have optimal product value effectiveness ($p < 0.01$), companies involved in antibiotics have optimal cost efficiency ($p < 0.1$), and companies involved in lifestyle diseases have the least-optimal cost efficiency ($p < 0.001$). Selection of a particular franchise may lead to deterioration of R&D productivity in the future.

Results indicate that out of 21 companies in 2007, 11 had optimal cost efficiency, two had optimal product value effectiveness, and one company had both. Companies with lower cost efficiency scores were more likely to actively engage in M&A ($p<0.05$) in 2007. Results indicate that in 2012, one company had optimal cost efficiency, two had optimal product value effectiveness, and no company had both. This dissertation also illustrates the cause of M&A among pharmaceutical companies, which was not explained by previous literature.

Statistical results indicate companies involved in vaccines were less cost efficient ($p < 0.001$) and those involved in the central nervous system (CNS) had the least product value effectiveness ($p < 0.001$), as shown in Table 1. In 2012, companies that developed cancer and respiratory therapies

($p < 0.001$) were less cost efficient. Franchise selection criteria may vary among companies but the criteria impacts future R&D productivity.

Based on analyses of R&D productivity among pharmaceutical companies, two alternatives are considered to sustain R&D productivity over the long term. First, to sustain R&D productivity over the long term, companies should focus on dominant therapeutic franchises and balance cost efficiency with product value effectiveness. Second, if a company becomes least optimal or fails significantly to catch up with the benchmark, pursuing M&A may no longer solve the decline of R&D productivity. As companies seek economies of scale and become successful, R&D spending increases and the sustainability issue arises. Companies have at least three options: 1) devote to potentially high-value products with high failure risk, 2) diversify therapeutic categories, and 3) collaboration.

The R&D productivity model and map measure an individual company's R&D productivity with two dimensions to visualize relative status in the pharmaceutical industry, and to indicate a possible solution to improve R&D productivity. While there are several useful R&D management tools, the R&D productivity map provides another way to inspect current R&D strategy. The map shows how to improve productivity by either complementing cost efficiency or product value effectiveness, or both.