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Evaluation of Operation Efficiency of High-Tech Industry with Application of Data Envelopment Analysis

Li WEI[1], Thomas WARD[2]

Abstract

High-tech industry is facing the globally competitive situation that the development strategy for technology industry to integrate national power, combine international resources, and conform to the market trend is required for developing the internationally competitive high-tech industry in China. Following high customization and the development of product diversification to conform to various customer needs as well as short product life cycle, it becomes more important to understand the relative business performance of high-tech companies to the industry in China and evaluate the strengths and weaknesses in order to rapidly respond to customer needs and maintain high-quality products. Modified Delphi Method is utilized in this study for selecting inputs and outputs. The variable data used in this study are acquired from open statistical data of enterprises. Data Envelopment Analysis (DEA) is further used for evaluating the efficiency. The research results conclude that 1 DMU shows strong efficiency, with better operation efficiency, 4 DMUs present the operation efficiency between 0.9 and 1 that the operation efficiency can be more easily enhanced, and 5 DMUs appear the operation efficiency lower than 0.9, with obvious inefficiency. Furthermore, inputs and outputs are gradually removed in DEA for understanding the sensitivity to efficiency. Finally, suggestions are proposed according to the results, expecting to assist high-tech industry in China in the business development.

Keywords: efficiency, evaluation, input, output, competitiveness, performance, success factors.

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Introduction

The development of science & technology and high-tech industry has advanced countries continuously maintain the high productivity in the next century and enlarge the development gap from underdeveloped countries. It is adverse for fairly sharing global resources in underdeveloped areas. China, being the largest developing country in the world, has to extremely stress on knowledge application and high-tech industry development strategies, which do not merely affect the economic development speed and international competitiveness of China, but would determine the realization of modernization goal in the next century. China used to attract foreign semiconductor companies setting up factories with the low costs of land and labor. Although there is the technological bases established by foreign-capital corporations, China has to face the threats from competitors in Southeast Asia and the technological advantage of advanced countries in Europe, America, and Japan. High-tech industry in China survive in the tight corner by flexibly coping with market changes and matching customers' product diversification and timeliness of delivery. Along with the development of new-generation technology, newly established semiconductor companies have to invest in high-end technology, enhance the quality and service, and constantly expand the industrial size. Besides, the complete industrial production cluster, overall effectiveness of economies of scale, and the competitiveness with low total production cost enhance the competitive advantage of China being the global supply chain.

High-tech enterprises are facing the changeable environment that the business strategies change from time to time; it seems that there is not a practicable and permanent business model. Such flexible adjustment to cope with environmental changes is also the business characteristics of high-tech companies. Semiconductor industry has been positioned as the industry to help investors make profits. However, along with the high customization and the development of product diversification to conform to various customer needs as well as short product life cycle, it is important to understand the relative business performance of high-tech companies to the industry in China and evaluate the strengths and weaknesses in order to rapidly respond to customer needs and maintain high-quality products. In this case, different resource characteristics of high-tech companies in China and the input and application efficiency should be understood, and competitive strategies should be set according to the resource capacity and performance to enhance the business performance and establish competitive advantages. The measurement of business performance of high-tech industry in China is therefore a primary issue for managers.

Literature review

Operation efficiency

For organizational management, Hirt & Willmott (2014) mentioned in the book, Management Science, that organizational management contained planning, organization, leadership, and control, aiming to achieve the goal set by an organization. Pinheiro, Hennart, & Gulamhussen (2016) regarded performance as the integrated concept to reflect organizational operation for presenting the organizational operation result, and performance was composed of efficiency and effectiveness. In regard to efficiency and effectiveness, Kang & Bekkers (2015) regarded efficiency as “doing things right” and effectiveness as “doing the right thing”. In consideration of essential and functional differences among organizations, performance cannot be measured with a general model. The evaluation of performance allows an organization seeing visions of things by experiences. The retrospect allows an organization understanding the effectiveness and efficiency in the past resource application, and the prospect allows the evaluation result being the reference for future business strategies and resource allocation (Xue, 2013). Armour (2015) also pointed out effectiveness in performance as the achievement of pursuing organizational goal, while efficiency stressing on the relationship between inputs and outputs to seek for minimizing resources. In other words, effectiveness referred to the achievement of goals set by an organization and efficiency was regarded as certain inputs for more outputs or certain outputs from fewer inputs. Under limited resources, it was necessary to think of the achievement of organizational goal as well as pay attention to achieving the goal more efficiently. Zhu & Yang (2016) used “earnings per share”, “sales growth”, and “profitability” as the standards for performance measurement. Hsu & Ziedonis (2013) proposed “technological innovation performance” as a part of business performance. Technological innovation performance mainly contained “product innovation performance” and “process innovation performance”, mainly measuring from the contribution of R&D expenditure, new product listing ratio, and product cost reduction or profit creation. Bruno *et al.* (2015) evaluated the overseas investment strategies and performance of Taiwanese enterprises with “sales growth”, “profit rate”, and “employee turnover”. Kao *et al.* (2015) compared business performance with “profitability”, “stability”, and “business capability”. The major evaluation indicators focused on profitability, productivity, and management effectiveness, including operating profit rate, net profit margin, debt ratio, total asset turnover ratio, and employee productivity.

Evaluation of efficiency

Cao & Zhao (2013) mentioned that the evaluation of efficiency was to measure the relative relationship between inputs and outputs of an enterprise. The evaluation result could be the standard of assessment as well as explain that managers' understanding of the allocation of internal resources of the organization being effectively utilized for developing the maximal function with limited resources. Kastelle, Hu, & Dodgson (2013) indicated that the "relative" concept was generally used for the evaluation of efficiency to compare the selected samples. The research on the evaluation of relative efficiency initiated from the production efficiency measurement proposed by Farrell, who estimated efficiency with "non-default production function". In such measurement, overall efficiency (OE) was classified into technical efficiency (TE), the actual transfer between inputs and outputs, and price efficiency (PE), or allocative efficiency (AE), the optimal combination of factor allocation. Ernst, Lee, & Kwak (2014) mentioned that Byrnes *et al.* divided technical efficiency into pure technical efficiency (PTE), scale efficiency (SE), and congestion efficiency (CE). Huang *et al.* (2013) mainly distinguished whether the lack of technical efficiency was purely the problem of production technique, caused by excessive production factors, or the problem of size. Various definitions of efficiency stand for different meanings of efficiency. Production efficiency in economics refers to technical efficiency and overall efficiency. Hall & Owings (2014) indicated that technical efficiency explained the idea to avoid resource waste, while overall efficiency referred to the idea expressing the most appropriate combination of inputs and outputs under known prices of inputs and outputs. Technical efficiency, overall efficiency, and scale efficiency are further explained as followings: (1) *Technical efficiency*: Technical efficiency mainly measures whether a production unit effectively utilizes factor of production to achieve the maximum yield with the least input resources for the lowest costs but the largest profits; (2) *Overall efficiency*: Allocative efficiency (or "price efficiency") measures whether a production unit engages in production with least-cost input combination, i.e. to maximize current allocative efficiency with the least-cost input combination, under relatively constant prices of inputs (Pohlmann, Neuhausler, & Blind, 2015): (3) *Scale efficiency*: Scale efficiency aims to measure whether a production unit maintains the optimum production scale for the production; and, the essential conditions for the optimum production scale is constant return to scale (Zumrah, Boyle, & Fein, 2013).

Research evaluation method

Selection of input/output

To combine expert opinions with the selection for input/output and avoid fuzziness in the survey process, Modified Delphi Method is utilized in this study for selecting input/output. Based on special considerations, brainstorming open-ended questionnaire is omitted, and the structured questionnaire is directly developed, after referring to large amount of literatures, for the first run questionnaire survey. It is regarded as Modified Delphi Method. Directly preceding the first run survey with the structured questionnaire could save a lot of time, and the structured questionnaire could have the experts immediately focus on the research subject, without guessing the open-ended questionnaire. Total 25 copies of questionnaire are distributed, and 18 valid copies are retrieved, with the retrieval rate about 72%. The variable data used in this study are acquired from open statistical data of enterprises.

Definitions of variables:

– Input variable: (1) Capital: total capital of a company; (2) Workforce: number of employees in a company.
– Output variable: (1) Total revenue: annual revenue (revenue growth).

Data analysis

Data Envelopment Analysis (DEA) is applied to evaluate efficiency in this study. Different from traditional Regression Analysis simply seeking for the average path from a series of data, DEA envelopes data of various samples and attempts to find out the relationship that it presents the advantage of a good efficiency evaluation model. The method applies linear planning, considers factors which could be used for measuring the performance among various evaluated units, and compares the performance of units with similar characteristics (Stiebale, 2013).

From the aspect of economics, Hu & Hung (2014) indicated that the fewer inputs but more outputs of a business revealed the better “performance” of the unit; and, “efficiency” could be used as the evaluation standard to measure such performance. With the comparison of inputs and outputs, efficiency could be defined as efficiency = sum of weighted output /sum of weighted input. The maximal output function acquired from different input combination is called “production function”, and the maximal outputs acquired from general inputs are smaller than the yield of production function. In this case, production function is the maximum frontier of various yields that it is also called “production frontier”. Bos, Kolari, & Van Lamoen (2013) explained the geometric meaning of efficiency that it utilized envelope principle to reflect inputs and outputs of all evaluated DMUs to the space for evaluating the relative efficiency of organizations and finding out the efficiency envelope for all observed data to form efficiency frontier.

The distance between the observation of individual DMU and efficiency envelope is calculated for the relative efficiency level.

Douglas, Janos, & Ross (2015) considered that Ferrel might be the pioneer in the field of efficiency measurement. He first proposed the idea of "production frontier", utilized the setting of isoquant curve, and regarded the track of the isoquant factor combination of corporations as production boundary to estimate the technical efficiency of individual corporation (relative to the best corporate). Tafti (2013) indicated that the measurement of efficiency with DEA was based on the efficiency of "Pareto optimality". Pareto optimality indicated that no-one could enhance another person's benefits without damaging the others' benefits. According to the viewpoint of efficiency, once "production boundary" was known (as the idea of envelope or efficiency frontier in economics), the actual production could be compared with production boundary to further measure efficiency. O'Cass & Sok (2013) indicated that DEA, with the idea of envelope, considered all DMUs' inputs and outputs and calculated the relative efficiency of individual corporation to other corporations by dividing weighted outputs by weighted inputs.

Results

Analysis of operation efficiency in high-tech industry

By substituting the input/output in this study into CCR and BCC models, the overall efficiency and pure technical efficiency of high-tech businesses' operation efficiency could be acquired; and then, the return to scale of high-tech businesses' operation efficiency could be acquired by dividing the two. Overall efficiency, pure technical efficiency, scale efficiency, and return to scale are organized in Table 1.

From *Table 1*, Hisilicon, with the overall efficiency=1, is relatively the most efficient high-tech company, while the rest high-tech companies show low overall efficiency, especially, Gigadevice Semiconductor, with the lowest overall efficiency, is relatively the most inefficient high-tech company. In other words, 9 DMUs, except 1 DMU with the overall efficiency=1, are relatively inefficient, possibly because they could not effectively apply inputs or do not achieve the optimum production scale. It requires further analyses.

Table 1: Efficiency of high-tech businesses

High-tech company	overall efficiency	technical efficiency	scale efficiency
Hisilicon	1.00	1.00	1.00
Tsinghua Unis	0.98	0.98	0.97
Sanechips	0.94	0.92	0.95
Huada Semiconductor	0.82	0.84	0.80
Huiding Technology	0.88	0.86	0.90
rockchip Electronics	0.90	0.90	0.90
Silan Microelectronics	0.91	0.92	0.90
Will Semiconductor	0.80	0.81	0.80
Vimicro	0.83	0.83	0.83
Gigadevice Semiconductor	0.75	0.72	0.78

Sensitivity Analysis

In this study, inputs and outputs are gradually removed for DEA to understand the sensitivity to efficiency. From *Table 2*: (1) The efficiency of all DMUs, after removing "capital", is lower than the original efficiency, presenting the higher importance of capital to all DMUs; (2) The efficiency of all DMUs, after removing "workforce", is lower than the original efficiency, revealing the higher importance of workforce to all DMUs; (3) The efficiency of all DMUs, after removing "total revenue", is lower than the original efficiency, showing the higher importance of workforce to all DMUs.

Table 2: Sensitivity Analysis of removal of single input and output step by step

DMU	original relative efficiency	Removing capital	Removing workforce	Removing total revenue
Hisilicon	1.00	0.90	0.83	0.97
Tsinghua Unis	0.98	0.93	0.84	0.92
Sanechips	0.94	0.86	0.80	0.88
Huada Semiconductor	0.82	0.73	0.76	0.78
Huiding Technology	0.88	0.85	0.80	0.83
rockchip Electronics	0.90	0.87	0.86	0.88
Silan Microelectronics	0.91	0.83	0.84	0.85
Will Semiconductor	0.80	0.72	0.70	0.76

Vimicro	0.83	0.78	0.76	0.77
Gigadevice Semiconductor	0.75	0.70	0.66	0.68
Number of efficient DMU	1	0	0	0

Data source: Organized in this study

Conclusion

From the efficiency acquired from DEA and the information of variables, 1 DMU (about 10% of all DMUs) presents strong efficiency, with the efficiency=1, revealing the better operation efficiency; 4 DMUs (about 40% of all DMUs) show marginal inefficiency, with the efficiency between 0.9 and 1, revealing that the operation efficiency could be more easily enhanced; and, 5 DMUs (about 50% of all DMUs) are obviously inefficient, with the efficiency<0.9, in which Gigadevice Semiconductor presents the lowest operation efficiency. Apparently, high-tech companies have to understand the relative advantages and weaknesses among inputs and outputs, as the performance of inputs and outputs might affect the overall business performance. High-tech companies therefore have to reinforce the resources on the weaker part to optimize the overall performance. Managers should collect the historical data of enterprises with better operation efficiency. The business strategies of inputs and outputs of high-tech companies with good performance as well as the changes of domestic and international business environment and markets are analyzed to assist mangers of high-tech companies with bad operation efficiency in concluding the key success factors for setting control and improvement strategies.

Suggestions

According to above conclusion of high-tech businesses' operation efficiency, the following suggestions are proposed in this study.

(1) The relatively inefficient high-tech company, in the research result, could explore whether there are too many resources not being effectively applied to result in waste and relatively producing lower-profit outputs with higher-cost inputs. The management level should completely understand the factors in inefficiency, improve the management strategies and cost control, and reinforce the quality of company to prevent from being eliminated in the market because of continuous worsening management conditions. The relatively efficient company should inspect the development trend of semiconductors and the changes of the business performance, continuously maintain good performance, establish stable business

basis for other companies' learning model, and lead the co-development of all high-tech companies to cope with the changeable economic environment.

(2) Semiconductor industry is essential in the economic system of a nation, and high-tech companies play the role of supplier in high-tech industry. For this reason, the government should focus on the healthy development of high-tech companies and high-tech markets. For high-tech companies with worse operation efficiency, the authority should play the role of supervisor to understand the factors in the inefficiency, provide timely assistance, and supervise the improvement to prevent the entire semiconductor market from being influenced by the bad management of inefficient high-tech companies.

(3) Systems are the root of many problems in China. High-tech businesses would not have the development space before the systems are improved. Consequently, it is necessary to accelerate the reform of enterprise systems and government systems to further improve the market economy and reinforce the government's financial capability to support the development of technology. In addition to continuing the decision of largely developing private technology enterprises, the transformation of research institutions into private technology enterprises should also be accelerated to release the productivity of technological resources with the market force for the reform of technology systems.

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