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Evaluating the Performance of Vertical Integration for Semiconductor Industry

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Abstract— *Taiwan's semiconductor industry has developed vertical integration flows in order to survive the competition. The aim of this research is to assist semiconductor companies to evaluate the operational efficiency and find the right partners for vertical integration by using the Malmquist productivity index. Realistic data are collected during the period of 2011 - 2015. The evaluation results demonstrate that the productivity growth of almost Taiwanese IC fabrication industry increased by 20.47% on average, mainly due to progression in technical change. The empirical result shows that there are four companies, TSMC, MXIC, Powertech Technology, and SPIL that estimate the productivity loss due to regression in technological change. The method of evaluation the vertical integration provides the best decision-making strategies for finding the suitable suppliers to improve business performance.*

Keywords— *Malmquist productivity index; Semiconductor; Decision making units; Vertical integration.*

I. Introduction

Semiconductor industry is one of Taiwan's key manufacturing industries. According to Taiwan semiconductor industry association [1], Taiwan's semiconductor industry involved of 240 IC fabless design companies, 16 fabrication companies, 37 packaging and testing companies, 7 substrate suppliers, 11 wafer suppliers, and 3 mask makers. Taiwan's semiconductor industry has developed upstream and downstream vertical integration to increase business profits. The revenue of Taiwan semiconductor including design, manufacturing, packaging and testing have become one of the leaders of the global semiconductor industry. In 2012, Taiwan semiconductor revenue ranked the fourth place following US, South Korea, and Japan, and accounted for 7.9% of the US$305.6 billion worldwide markets. Thus, Taiwanese firms play a crucial role in the semiconductor industry.

However, in recent years, semiconductor technology or applications for smart phones are more advanced and more complicated than in the past. This makes companies in the semiconductor industry are extremely competitive. Facing with that problem, vertical integration is known as a useful strategy helps semiconductor companies creating value together and sustainable development in fierce market competition.

According to Cousins [2], vertical integration or vertical collaboration is one type of strategic alliance. This is a long-term relationship among members through reductions in transaction costs, increase in resource sharing, learning, and sharing of knowledge. The benefit of vertical integration comes from the greater capacity. It gives organizations to control access to inputs [3]. Moreover, collaboration manufacturing also helps to reduce supply risk, administration cost, improve networking benefits as group members communicate and interact with each other [4]. Cruijssen [5] mentioned that collaboration is highly desirable for the semiconductor industries to ensure global business opportunity. A number of studies have proposed that vertical integration can make a direct effect on firm operating performance [6-9].

Due to more competitive pressure, semiconductor companies are now looking value chains for horizontal and vertical collaboration with suitable partners to achieve the business productivity and performance. Although many studies have been identified the important dimensions of vertical integration, the research on the comprehensive evaluation of the performance of vertical integration for semiconductor industry has been limited. The current research proposes a systematic and structured framework for performance evaluation in the semiconductor industry which can also be extended to a wide range of industries in the high-tech sector. The proposed performance measurement system uses data envelopment analysis (DEA) to evaluate semiconductor companies as decision making units (DMUs). The semiconductor industry plays an important role on the development in Taiwan. However, there is no study implemented DEA- Malmquist productivity index (MPI) for measuring the efficiency of Taiwan semiconductor industry. Thus, this paper applied MPI to evaluate the performance of semiconductor companies in Taiwan. The study helps company's manager chooses the suitable partner of vertical integration to create more benefits and reduce risks. This also provides suggestions to semiconductor companies in making integration.

II. Literature Review

A. *Overview of the Data Envelopment Analysis (DEA)*

Company's operational progress relies on inputs and outputs improvement. The method of data envelopment analysis (DEA) can be easily applied to evaluate the effectiveness of multiple input-output frameworks to compute the index of operational efficiency. DEA is a method in operations research and economics for the estimation of production frontiers [10]. It is used to empirically measure productive efficiency of decision making units (DMUs). Since the work by Charnes [11], DEA has rapidly grown into the field of operations research, management research and economic research. Hood [12] applied the DEA to discuss the direct and control of material in process and produce performance of IC foundry industry. Kim and Lee [13] used DEA Malmquist to measure the spillover of manufacturing technology R & D. Chen and Yeh [14] implemented DEA to analyze the comparative performance of six high-tech industries that developed exist in Taiwan. The six high-tech industries are semiconductors, computers, communications, photo-electronics, precision equipment, and biotech. The results indicated that the semiconductors and computer industries are the best performance. The Malmquist productivity index (MPI) in DEA has proven to be a very useful tool for measuring the productivity changes of DMUs in the past several decades. For instance, Liu and Wang [15] implemented MPI to analyze the productivity changes of Taiwanese semiconductor companies in the time period from 2000–2003. Babu and Natarajan [16] used Malmquist productivity index to evaluate the extent of regional manufacturing performance in India. The results pointed out that labour productivity diverges in the reform era and its growth and TFPG follow more or less a similar pattern. Wang [17] implemented MPI to selecting and evaluating green logistics providers for sustainable development. They noticed that Knight Transportation and the Union Pacific Corporation are achieving positive technical change. Wang [18] applied MPI to estimate the energy efficiency of seventeen countries. The result indicated that the United States, Columbia, Japan, China, and Saudi Arabia perform efficiency in energy. In recent years, there are many researchers have been implemented DEA to investigate the efficiency performance of semiconductor companies [19-22]. While previous scholars applied DEA models to evaluate the operation performance of semiconductor companies, they neglect vertical integration measurement among companies which is one of the strategic developments for the semiconductor companies. The current study has applied MPI to assess the efficiency performance of Taiwan's semiconductor industry through vertical integration. The proposed method of the economic evaluation of semiconductor companies, aimed to improve business performance, provide a useful tool for supporting in vertical integration decisions.

III. Proposed Methodology

This study used Malmquist Productivity Indexes (MPI) to evaluate the performance of vertical integration for semiconductor industry. The research procedure is showed as figure 1.

The first stage is primarily collecting the information of semiconductor companies. This reseach selects six main publicly traded wafer fabrication companies and seven main IC packaging-and-testing companies in Taiwan to consider whether to have vertical combination. Therefore, there are 42 combinations (6 × 7). The second stage is collecting input and output indicators. For this stage, the study has checked the correlation between input and output factors. If this is not satisfied with the DEA assumption, we need to consider and choose other input and output factors. The third stage is to analysis the operating performance of semiconductor companies before and after vertical integration through the parameters of Malmquist, catch-up and frontier-shift. The fourth step gives conclusion and suggestion.

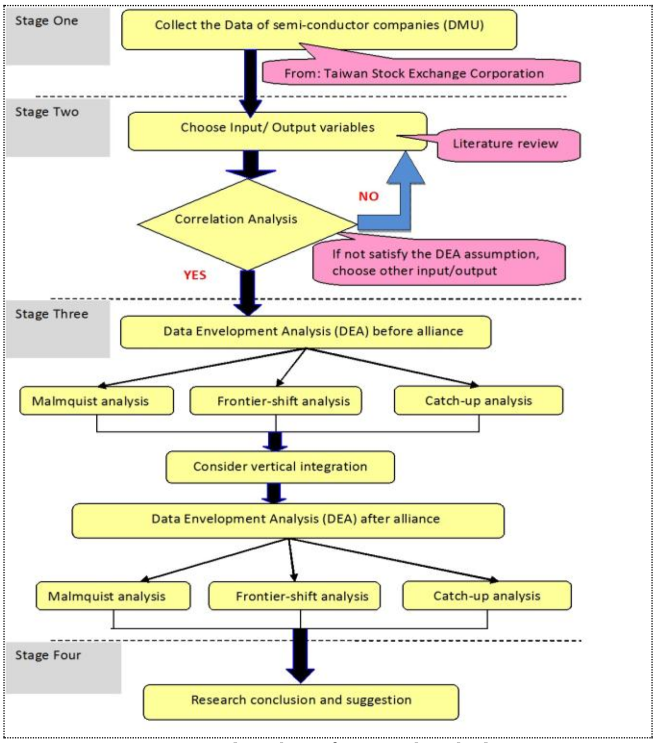

Fig. 1. Flow chart of proposed method.

Stage One: Collect the data of semiconductor companies

- The study applied Malmquist index to find which combination has the highest productivity growth in semiconductor industry.
- Observe semiconductor industries in Taiwan to find all potential candidates to be DMUs list.
- Financial data is collected from Taiwan stock exchange cooperation during 2011-2015. All companies will be classified into two categories: up-stream and down-stream.

Stage Two: Choose Input/ Output Variables:

Based on the literature review mentioned previously and the key elements of the operation for semiconductor industry. The study selected for four input factors including fixed assets, current assets, operating expenses, R & D expenses. Output factors including profits before tax and operating revenue. These factors are important to semiconductor industry. Moreover, before applying DEA method, the research assumes that input and output variables have to meet the isotonicity. It means when input quantity increase; output quantity cannot decrease under same condition. The current study shows positive correlations between input and output variables.

Stage Three: Data Envelopment Analysis:

The correlation analysis was carried out to examine whether the selected input and output factors are both positive correlation. According to the Malmquist model, the research analyzed the condition of efficiency frontier-shift and technical change between the periods of 2011-2015. Then, making a comparison between productivity change, technical efficiency change and technical change to understand the performances of each decision making unit before and after virtual alliance. After that, setting up the vertical integration for semiconductor companies and providing the suggestion for vertical integration.

Stage Four: Research Conclusions and Suggestions:

The fourth stage is to summarize the ranking results of the DMUs and makes suggestions of how to integrate with the suppliers, fend off the external competitors, and correct the shortcomings of vertical integration. Thus, managers can enhance the competitiveness of enterprise.

IV. EMPIRICAL RESULTS

A. *Case study: Taiwan Semiconductor Industry*

This study used IC fabrication companies and IC packaging-and-testing companies in Taiwan as DMUs. Thirteen Taiwan's IC industry companies were selected for evaluating. Company A-F are Taiwan's IC fabrication companies and Company G-M are Taiwan's IC packaging-and-testing companies as Table I. To reach the goals of vertical integration, the research combines one IC fabrication company (up-stream) and one IC packaging-and-testing company (down-stream). Then, analyze the efficiency change of the competitive consequences of vertical integration.

TABLE I. Taiwan's IC Industry company list.

Code	Company
A	UMC
B	TSMC
C	Winbond Electronics
D	Inotera Memories
E	MXIC
F	Mosel Vitelic
G	Powertech Technology
H	Walton Advanced Engineering
I	Formosa Advanced Technologies
J	ASE
K	King Yuan Electronics
L	Sigurd Microelectronics
M	SPIL

Table II shows that there are three companies with MPI larger than 1, which indicated that productivity growth in this period, the remaining three companies with MPI less than 1, it means that productivity loss in the period of 2011-2012. Company B had the highest productivity growth; followed by company A. Company F had the highest loss. From 2012 to 2013, all the companies had productivity growth except for company B and D. The study found that company B had the highest productivity loss. From 2013 to 2014, three of the companies had productivity growth. Company D had the highest productivity growth. From 2011 to 2015, only two companies that are D and E indicated that productivity loss.

Over the last five years, there were two periods (2012-2013, 2014-2015) showed that the productivity gains. Average Mamlquist Index in the period of 2014-2015 recorded the highest growth, 20.47%. However, there were two periods (2011-2012, 2013-2014) indicated that the productivity loss.

TABLE II. Annual productivity change of company A-F from 2011 to 2015.

Malmquist	2011-2012	2012-2013	2013-2014	2014-2015
A	1.194	1.025	0.765	1.460
B	1.854	0.852	0.685	1.336
C	0.772	1.180	1.090	1.657
D	0.461	0.522	1.384	0.707
E	1.021	1.532	1.285	0.509
F	0.350	1.087	0.578	1.556
Average	0.942	1.033	0.964	1.204

Table III presents the results of these MPI for the seven Taiwan IC packaging-and-testing companies for the years 2011-2015. From 2011 to 2012, many companies indicated that productivity loss while company L and M showed productivity growth. Company H had the highest loss. From 2012 to 2013, all companies had productivity loss except for company J. In the period of 2014 to 2015, all companies had productivity growth except for company M.

Over the last five years, all most companies had productivity gain during the period of 2014-2015. However, the Average Malmquist Index in the period 2013 -2014 recorded the productivity loss, -14.59%.

TABLE III. Annual productivity change of company G-M from 2011 to 2015.

Malmquist	2011-2012	2012-2013	2013-2014	2014-2015
G	0.896	0.789	0.771	1.258
H	0.793	0.856	0.861	1.274
I	0.869	0.862	0.725	2.245
J	0.824	1.060	0.782	1.829
K	0.908	0.783	0.728	1.680
L	1.041	0.876	1.101	1.656
M	1.121	0.774	1.010	0.976
Average	0.922	0.857	0.854	1.560

B. *Taiwan Semiconductor Industry Productivity Analysis after Virtual Alliance*

In this research, we try to figure out whether companies need to alliance. Firstly, we classify all companies into two categories. Company A, B, C, D, E and F (IC fabrication firms) are in up-stream; Company G, H, I, J, K, L and M (IC packaging-and-testing companies) are in down-stream. Given that the Malmquist productivity index of productivity change is a multiplicative composite of efficiency and technical change. In other word, the productivity losses described the result of either efficiency declines, or technique regresses, or both.

1) *Components of the Malmquist productivity index: Catch-up*

The results of technical efficiency change scores are shown in Table IV, following by a measure of productivity growth (MPI). "Catch-up" effect is so-called "technical efficiency change". The change values for technical efficiency are bigger than 1, which indicate that the DMU improve in technical efficiency. Table 4 shows the average efficiency change from 2011 to 2015.

Hong-Xuyen Thi Ho and Chia-Nan Wang, "Evaluating the performance of vertical integration for semiconductor industry," *International Research Journal of Advanced Engineering and Science*, Volume 2, Issue 4, pp. 109-114, 2017.

TABLE IV. Average productivity change and its components from 2011 to 2015.

Virtual Alliance company	Catch-up	Frontier	Malmquist
A	1.126	0.999	1.129
B	1.135	0.910	0.993
C	1.072	1.048	1.137
D	0.952	1.108	0.817
E	1.203	0.945	0.986
F	0.941	0.916	0.907
G	1.014	0.937	0.949
H	0.903	1.223	0.950
I	1.101	1.023	1.175
J	1.029	1.004	1.037
K	0.994	1.009	1.025
L	1.152	1.024	1.168
M	1.027	0.927	0.948
A+G	1.130	0.996	1.126
A+H	1.117	1.004	1.124
A+I	1.125	1.002	1.132
A+J	1.109	1.019	1.143
A+K	1.118	0.999	1.123
A+L	1.126	0.999	1.128
A+M	1.078	0.987	1.059
B+G	1.131	0.907	0.989
B+H	1.127	0.911	0.992
B+I	1.130	0.910	0.994
B+J	1.115	0.929	1.004
B+K	1.128	0.910	0.995
B+L	1.132	0.910	0.993
B+M	1.108	0.910	0.972
C+G	1.082	1.045	1.140
C+H	1.046	1.060	1.118
C+I	1.064	1.072	1.151
C+J	1.078	1.005	1.091
C+K	1.044	1.055	1.119
C+L	1.055	1.051	1.118
C+M	1.053	1.027	1.082
D+G	0.838	0.944	0.748
D+H	0.849	1.100	0.872
D+I	0.949	1.136	0.857
D+J	1.052	1.053	1.039
D+K	0.852	1.019	0.833
D+L	0.846	1.084	0.865
D+M	0.922	1.015	0.909
E+G	1.079	1.027	1.083
E+H	1.056	0.984	1.049
E+I	1.042	1.028	1.056
E+J	1.044	1.013	0.984
E+K	1.027	1.015	1.037
E+L	1.114	0.979	1.091
E+M	1.033	0.924	0.946
F+G	1.002	0.910	0.919
F+H	0.858	0.969	0.812
F+I	1.017	0.941	0.986
F+J	1.000	0.992	0.999
F+K	0.915	1.005	0.946
F+L	1.007	0.928	0.970
F+M	1.020	0.928	0.946

Although company A showed improvement in efficiency during the last five years, we can find out company A+G would have better efficiency than company A. On the other hand, company B also showed improvement in efficiency during the last five years although company B integrates with other company will have declined in efficiency change. It matches the recent news that TSMC want to do all the business on their own.

There are four companies including company D, F, H, K, with an efficiency change less than 1 over the last five years. Company D failed to improve efficiency during those years but if company D had vertical alliance with company J would have efficiency change scores greater than 1. Company F+H and company F+K still failed to improve their efficiency.

2) Components of the Malmquist productivity index: Frontier-Shift

Technique change, or the so-called "innovation" or "frontier-shift" effect is the second component of the Malmquist productivity change index. Table 5 shows the average technique change from 2011 to 2015.

The average technique change scores are smaller than 1, which indicate that innovation deteriorated in this period. In IC fabrication industry, innovations of companies tend to deteriorate, that means, the change values for these companies are smaller than 1 except for company C and D. Those companies did not invest in new technologies (methodologies, procedures and techniques) may cause the reason. Company B integrates with each IC packaging-and-testing company (G-M) can have innovation progress. Conversely, company F has technical regress (innovation deterioration) after alliance except for company F+K.

3) Productivity changes: the Malmquist productivity index

According to average MPI, company A, C, I, J, K and L, with MPI lager than 1, which means that productivity growth in the period, with the remaining MPI less than 1, which means productivity loss. Both companies A+I and A+J will have higher productivity growth than company A. Besides, both companies C+G and C+I will have higher productivity growth than company C. Company C+I had the highest productivity growth, 15.14%. We classified annual average Malmquist index in Table V.

TABLE V. Classification performance (MPI) of virtual alliance.

IC fabrication company	Virtual Alliance (Vertical Integration)	Score (MPI)	Rank
A	A+J	1.143	1
	A+I	1.132	2
	A	1.291	3
B	B+J	1.004	1
	B+K	0.995	2
	B+I	0.994	3
	B	0.993	4
C	C+I	1.151	1
	C+G	1.140	2
	C	1.137	3
D	D+J	1.039	1
	D+M	0.909	2
	D+H	0.872	3
	D+L	0.865	4
E	E+L	1.091	1
	E+G	1.083	2
	E+I	1.056	3
	E+H	1.049	4
F	F+J	0.999	1
	F+I	0.986	2
	F+L	0.970	3

According to Table V, the study analyses the average productivity change (MPI) and makes a recommendation to those IC fabrication companies. Even though company A and company C already have productivity growth (MPI>1) in this period. We can find out that company A+J will be the best. Conversely, company C+J will not be better than company C. Company C+I will be the best. However, company B, D, E and F have productivity loss (MPI<1). Company B and D only cooperate with company J can make the MPI values lager than 1. Conversely, company E only cooperates with company L will be the best. On the other hand, company F cooperates with any IC packaging-and-testing company can have bettered productivity but still cannot make the MPI values lager than 1.

V. Conclusions

Company performance efficiency is one of the important indicators to evaluate a company's potential growth; as only as resources could be allocated properly. In order to solve above problems, the study try to find the vertical integration partners from up-stream and down-stream. For sustaining higher efficiency performance, IC companies must remain innovative and keep a constant focus on core technology, service and support - especially during down times to maintain customer satisfaction, quality and serviceability.

The purpose of this study is to provide semiconductor companies some useful suggestions by using the Malmquist model. The Malmquist overall productivity indicator can be deduced from the rising direction or the declining direction of technical efficiency (Catch-up) or technical level (Frontier). The productivity loss for company B, E, G and M was mainly driven by the technological regress; the results indicate that those companies need the product innovation or technology development to enhance production technology. However, productivity loss for company D and company H was mainly driven by a decline of "catch-up" effect.

With different years, the priorities are different. On the whole, the productivity growth of Taiwanese semiconductor industry over the past five years is positive. Efficiency change was more impact than technique change in terms of contribution to MPI improvement. However, both "catch-up" and "innovations" or "frontier-shift" effects were predominately attributed to Taiwan semiconductor industry productivity growth.

This study has estimated the sources of productivity change for Taiwan's semiconductor industry during the period of 2011-2015. The change of MPI from 2011 to 2015 also reveals the trend within a 5-year period before integration. For IC fabrication industry, there were two periods (2012-2013, 2014-2015) showed productivity gains. Average Malmquist Index in the period 2011-2015 recorded the highest growth, 20.47%. However, there were two periods (2011-2012, 2013-2014) showed productivity loss. For IC packaging-and-testing industry, there is one period (2014-2015) showed productivity gains. However, the Average Malmquist Index in the period 2013-2014 recorded the productivity loss, -14.59%.

Research and development performance are very different among the evaluated companies, though most of the companies are technically efficient. In particular, the research found that most of the inefficient companies should increase their economic scales. Based on the empirical research, company J is a down-stream company. It had better productivity performance compared with other IC packaging-and-testing companies in Taiwan. However, based on the classification performance of virtual alliance. The result showed that company J is not a good partner for company C and E (up-stream). It means that not a company with the best performance would be the best partner. Thus, decision-makers need to consider further expansion of market and update knowledge of new technology. The study is not only helpful in finding weaknesses for the technical level but also helps company managers can assess suppliers capacity to choose the right partner for making business alliance.

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