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以階層式 DEA 模型評估台灣 TFT-LCD 產業經營績效

Hierarchical DEA Model for the Efficiency Evaluation of Taiwan's TFT-LCD Industry

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Abstract

This study shows how to use the Hierarchical DEA model to evaluate the operational efficiency of the manufacturing industry's production chain. We used nine TFT-LCD production chains in Taiwan with the data of 2001~2003 as example. Our model can distinguish the inefficiency between upstream and downstream firms, and the method combines two DMUs into one which allows managers to evaluate the relative inefficiency between industries. Furthermore, we show that if the TFT-LCD firm and LCD-monitor firm of one production chain were inefficient in the same part, it mean both of their fixed assets or human resource are relatively larger, then the production chain is inefficient. Almost all of the TFT-LCD firms and LCD-monitor firms of Taiwan's production chains were not suitable enough for each other in 2001~2003. It might be due to the fact that the managers of these firms ignored the efficiency of their production chain.

Keywords: data envelopment analysis (DEA), efficiency, hierarchical structured units, TFT-LCD

JEL classification: D24

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1. Introduction

Data Envelopment Analysis (DEA) is a mathematical programming approach to efficient measurement for each member in an organization, say, a set of decision making units (DMUs). A DMU is said to be relatively efficient if it locates on the efficiency frontier, pronounced no other DMU can produce the same amount of output with less resource input.

The merit of DEA model is that can solve multiple inputs and multiple outputs, can ignore the calculated unit without affecting the efficiency value. The vector of the weights for output and input are evaluated objectives However, the conventional DEA models merely focus on the measurement of productive efficiency in a single-stage operation; that is, a cross-sectional analysis for the whole production chain of the industry (e.g., Kerstens 1996, Tofallis 1997, and Seifert and Zhu 1998). This method makes no assumptions concerning the internal operating processes of DMUs. It is less valuable for managers to decide which section of DMU should be promoted when inefficiency is present.

Castelli et al. (2001) introduced a DEA model, which relaxes the assumption of homogeneous DMU, to assess the efficiency of interdependent sub-units within a larger DMU with the sense that part of the output of one unit may be the input of the others. Sexton and Lewis (2004) used this knowledge to described two-stage DEA model, with output of the first stage becoming the input of the second stage, furthermore, they established separate efficient frontiers for Stage 1 and Stage 2. The advantages of two-stage DEA model over single stage DEA model is that it can distinguish inefficiency occurring on the first or second stage.

However, these two stages of DEA model merely analyze internal structure of the single stage's decision-making units. In fact, this model merely dismantles the single stage DMU into two stage DMUs and measures the efficiency of single stage of organizations. Yet some industries' managerial efficiency are highly dependent on its upstream or downstream in reality. Such situation occurs in organizations with high percentage of production cost or revenue caused by their upstream or downstream firms, such as the Liquid Crystal Display (LCD) monitor industry. Due to 70%-80% of the cost of LCD monitor is upon LCD, their managerial performance is highly influenced by the large size Thin Film Transistor Liquid Crystal Display (TFT-LCD) manufacturers, say, are their up-stream firms. Further-more, LCD-monitor manufacturers consume about 65% ~70% of large-size TFT-LCD manufacturers' products, thus these two industries have high relation in profit[1].

Taiwan's large size TFT-LCD industry can be divided into three classes. The first is upstream industries; the set of manufacturers which manufacture the semi-finished goods to use as the input factors of production TFT-LCD, such as Color Filter factories, Glass Substrate factories and Backlight module factories etc. The second is the middle-stream industry; the set of manufacturers which produce large-size TFT-LCDs. And the last one is the downstream industries; including LCD monitor manufacturers, notebook computer manufacturers and LCD-television manufacturers, which use the large-size TFT-LCD as the main input factor (Chang 2005).

This thesis discusses the efficiency of the Taiwanese LCD-monitor industry. As these firms' performance are highly dependent on the TFT-LCD industry, it might be unfair in measuring their performance value merely on analysis of their managerial effectivity. Hence to solve this problem we would like to consider not only the efficiency of downstream LCD monitor firms but also its upstream TFT-LCD firms. In other words, the major objective of this issue is to measure performance of the production chains of TFT-LCD ~ LCD monitors.

To do this, we also distinguished that the inefficiency is due to up or downstream firm. Say, we like to measure three kinds of efficiency of these production chains, (1) production chains' efficiency (2) upstream efficiency (3) downstream efficiency. Hence we can compare the firms' efficiency in each stage to observe the reason of inefficiency.

In order to measure the efficiency of LCD monitors production chains, we would like to use the knowledge of Hierarchical DEA-like Model (Castelli et al 2004), a kind of two-stage DEA which is a model of the internal structure of the DMUs. Hierarchical models each DMU as two sub-DMUs connected in series, with output

[1] Source: Taiwan Institute of Economic Research.

from the first stage sub-DMU becoming the input to the second stage of sub-DMU It means that the second stage consumed all of the output of the first stage immediately. Unfortunately, our target, TFT-LCD~LCD monitor production chains do not have such characteristics., LCD monitor firms will not consume all of TFT-LCD outputs, and LCD monitor's inputs resource are not all over from TFT-LCD products.

In order to fit this situation, we will consider the opposite in the point of view of Hierarchical DEA-like model. It means we are going to combine two DMUs as one to measure the efficiency of production chains. Say, we would like to combine two efficient frontiers of two stream into single common one. The evaluation of relative efficiency may be embedded in more aggregate models (Athanassopoulos, 1998). We multiply upstream and downstream objective functions as our new objective functions. Since the outcome terms of upstream do not equal to the resource that the downstream used, the objective function we defined is the multiplication of two terms where each is the weighted ratio of products over the consumed resources as the result.

2. Purpose of research

TFT-LCD and LCDmonitors are two manufactories which are highly-related on cost, considering the source of input factors and route of sales, vertical integrating being one way for managers to raise their earnings. Hence to trade with the right firms become important, and they have to know which production chain of which firm they trade with have higher efficiency, and how they should change themselves. This article brings up some suggestions as follow:

(1) To measure the efficiency of the production chain of Taiwan's TFT-LCD~LCD monitors.

(2) If inefficient, what reasons caused the production chain's inefficiency. Is it due to the inefficiency of upstream TFT-LCD firms or downstream LCD monitor firms, or both of them.

(3) What should they do in order to increase their efficiency.

3. Manufacturing Industry of TFT-LCD

The idea of Liquid Crystal Display (LCD) came to during the late 19th century, but the technique of LCD has been workable since the 1960s. The technique of LCD was developed by Radio Coporate of American (RCA) in 1968. After RCA issued their LCD technique in Japan, it was developed in Japan. At that period, the technique of LCD was named Twisted Nematic Liquid Crystal Display (TN-LCD). As time passed by, LCD technology started developing, for example, Super Twisted Nematic Liquid Crystal Display (STN-LCD) in 1980s, Thin Film Transistor Liquid Crystal Display (TFT-LCD) in 1990s…etc..

Table.1 :Kinds and properties of LCD

<table>
<tr><td colspan="6">Liquid Crystal Display (LCD)</td></tr>
<tr><td rowspan="4">Kinds</td><td colspan="2">Passive Matrix Drive (PM)</td><td colspan="3">Active Matrix Drive (AM)</td></tr>
<tr><td rowspan="3">Twisted Nematic (TN-LCD)</td><td rowspan="3">Super Twisted Nematic (STN-LCD)</td><td colspan="3">Thin Film Transistor (TFT-LCD)</td></tr>
<tr><td>a-Si TFT</td><td colspan="2">Poly-Si TFT</td></tr>
<tr><td>Simple TFT-LCD</td><td>Low Temperature Poly Silicon (LTPS)</td><td>High Temperature Poly Silicon (HTPS)</td></tr>
<tr><td>Period</td><td>1970s</td><td>1980s</td><td colspan="3">1990s</td></tr>
<tr><td>Side</td><td><2″</td><td>2″~10″</td><td colspan="3">Many Sides</td></tr>
<tr><td>Color</td><td>Black and White</td><td>Colored</td><td colspan="3">Colored</td></tr>
<tr><td>Display</td><td>Word</td><td>Picture</td><td colspan="3">Animated</td></tr>
<tr><td>Goods</td><td>Calculator etc..</td><td>Cellular, PDA and Notebook etc.</td><td colspan="3">LCDmonitors, LCD-TVs and Notebooks.</td></tr>
</table>

Source: Edited by self

Now, the top TFT-LCD industries are Japan, Korea and Taiwan. As for Japan, from the 1970s Japan Sharp company transformed the technology of LCD to goods, and Japan became the leader country of LCD production with respect to upstream elements, middle-stream LCD production or downstream goods. For Korea developed LCD and upstream elements' techniques in the late 1980s, and became another leader in the LCD market successfully. Although Taiwan had been researching large-size TFT-LCD since 1992, actually they produced later than Korea. Fortunately, according to the demand of market, support by government, and technology-cooperation overseas, Taiwan became one of the main countris in theproduction of TFT-LCD.

Up-stream's main input elements of large-size TFT-LCD industry can be divided into Color Filter, Drive IC, Back Light, Glass Sub, Polarized Light Board and other materials. Downstream goods are NB, LCD-TV, LCD monitor etc… We can figure out the relation of TFT-LCD industry diagram as:

The whole TFT-LCD industry structure can be divided into upstream material market, middlestream TFT-LCD market and downstream various manufacturer market as shown in Figure.1.

3.1 TFT-LCD Industry in Taiwan

Taiwan's LCD industry was started by Jin Ye Electronic and Chong Shan Technology in 1970s, and Si Tai Electronic in 1980s, but they all went bankrupt one by one due to depression. Nevertheless, LCD technique was being developed in local individual labs. In the 1990s, downstream marker structure stepped into NB using large-size STN-LCDs. Picvue Electronics, Nan Ya, Wintek Technology, BySources Technology invested in this industry. At the same time small-size TFT-LCD technique appeared in Japan and Korea. In Taiwan, Unipac Optoelectronics, and Prime View International invested in small size (3~6inches) TFT-LCD's factories in Hsin Chu in 1994 and 1995. But the large-size TFT-LCDs were still imported from abroad. As the domestic downstream's NB market was growing, large-size TFT-LCD demand was growing too, so ChungHwa Picture cooperated with Japan Mitsubishi Motors and invested in the production of 12.1 TFT-LCD in 1997. Chi Mei Optoelectronics, Hannstar, Acer Display Technology、Unipac Optoelectronics、Quanta Display also invested in large-size TFT-LCD production in 1998 and 1999. As time went by, Taiwan became one of the leaders

In Taiwan, main downstream demand of large size TFT-LCD was chiefly in Notebook computers, LCD monitors and LCD TVs. Of course it also included communication, livelihood demand, and car communication manufacturers market. These demands promoted the production of TFT-LCD. And the growth of the

TFT-LCD industry promoted the construction of upstream material supply industry.

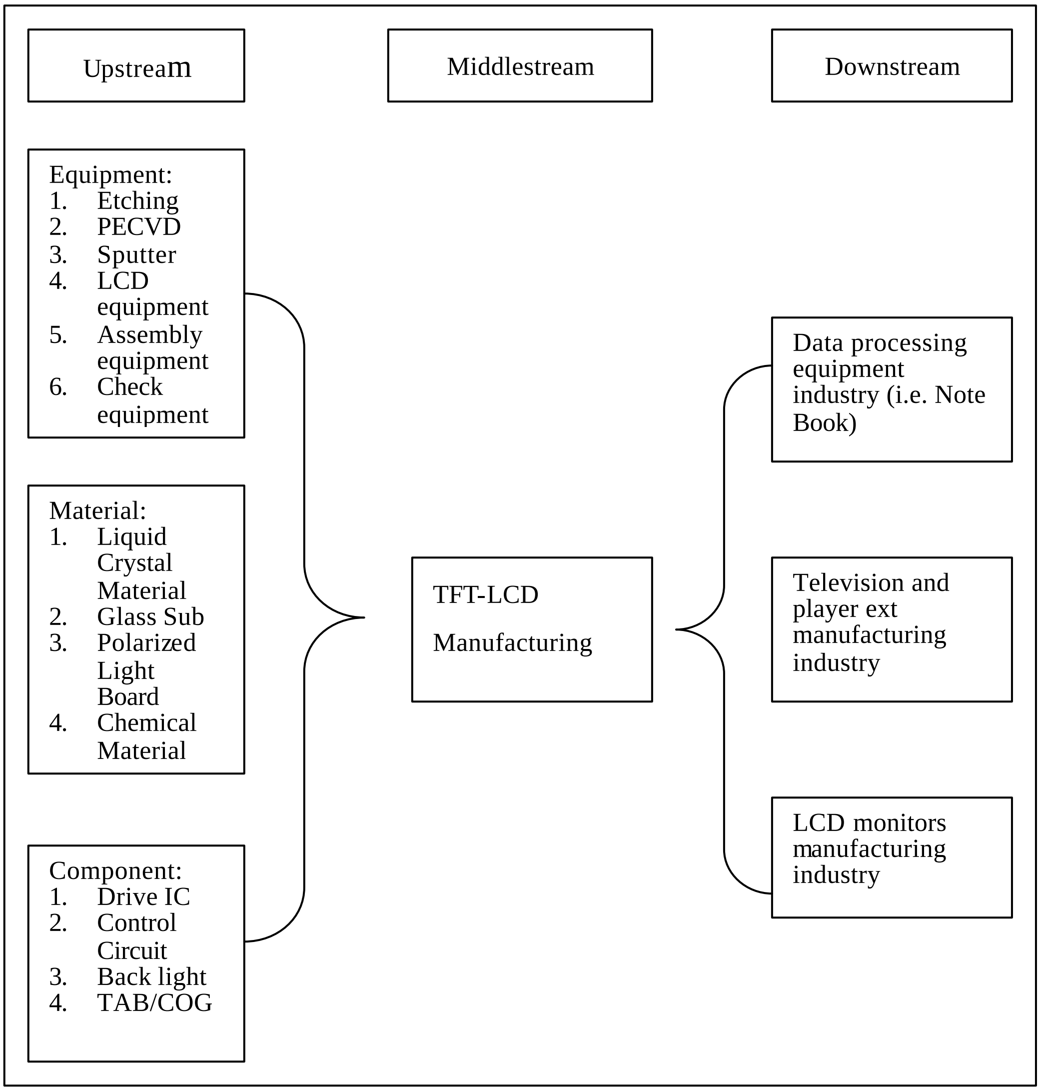


Figure 1: TFT-LCD-industry relational diagram

Source: Taiwan Institute of Economic Research (TIE)

Today, large-size TFT-LCD is one of the major industries of Taiwan. The TFT-LCD five tigers are: AU OPTOELECTRONICS (combination of Acer Display Technology and Unipac Optoelectronic), CHUNGHWA PICTURE TUBES, LTD (CPT), HANNSTAR OPTOTECHNOLOGY, CHI MEI OPTOELECTRONICS CORP (CME), QUANTA OPTOELECTRONICS (Those who invested in various generation of TFT-LCD manufactures See Table 2 and Table 3 showing the various generation versus size of TFT-LCD.)

Manufacturers	Factory located	Generation	Quantity of output/month (thousand slices)	Periods of mass production	In use of
CPT	Taoyuan	G3	36	1999/05	Monitor, NB
		G4	73	2001/05	Monitor, NB
		G4.5	75	2003/05	Monitor, NB, TV
	Lung Tan	G6	9	2005/Q4	Monitor, TV
	Taichong Science Park	G7.5	N/A	N/A	N/A
CME	Tainan Science Park	3.5	65	1999/07	Monitor, NB
		G4	88	2001/10	Monitor, TV
		G5	120	2003/08	Monitor, TV
		G5.5	65	2005/Q2	Monitor, TV
		G7.5	N/A	N/A	N/A
Hannstar	Taoyuan Fab1	G3	55	2000/03	Monitor, NB
	Taoyuan Fab2	G3	55	2001/05	Monitor, NB
	Tainan Science Park Fab3	G5	60	2004/03	Monitor, TV
	Tainan Science Park Fab4	G6	N/A	N/A	N/A
Quanta	Taoyuan L1	G3.5	50	2001/12	Monitor, NB
	Taoyuan L2	G5	47	2003/04	Monitor, TV
	Taoyuan L3	G6	90	2005/Q4	Monitor, TV
AU OPTRONICS	Hsin Chu L5	G3.5	60	1999/07	Monitor, NB
	Taoyuan L6	G4	60	2000/06	Monitor, NB
	Taoyuan L8A	G5	50	2003/04	Monitor, TV
	Taoyuan L8B	G5	70	2004/02	Monitor, TV
	Taichung Science Park L10	G6	60	2005/Q1	Monitor, TV
	Taichung Science Park L12	G7.5	N/A	N/A	N/A

Table 2: Taiwan large-size TFT-LCD generation spread.

Source: Taiwan Institute of Economic Research

Generation	Size (mm^2)
G2	370*470
G3	550*650
G3.5	600*720
G4	680*880
G4.5	730*920
G5	1,100*1,250
G5.5	1,300*1,500
G6	1,500*1,850
G7	1,800*2,000
G7.5	N/A
G8	N/A

Table 3:Taiwan large-size TFT-LCD generation vs. side.

Source: arrangement from TIE

Since Taiwan TFT-LCD industry was invested in later, and established G3.5 factory to be the start, hence the production of large size TFT-LCD was emphasized in 14″, 15″and 17″. They take almost more than 90% of all produced TFT-LCDs in Taiwan. As for the example in 2003, 15″ took 54.48%, 17″took 26.59% and 14″ took 12.16% of all production. (see Table 4 below)

Size	Share(%)
14 inches	12.16
15 inches	54.48
17 inches	26.59
19 inches	3.49
Others	3.29

Table 4: Domestic TFT-LCD market structure in 2003

Source: Market Intelligence Center

3.2 Cost structure of large-size TFT-LCD

Although in recent years upstream factories have appeared in the domestic market, but the chief TFT-LCD industries' upstream input factors have depended on import, the price of which doesn't change at all even though the price of TFT-LCD is decreasing yearly. Again since the TFT-LCD is a capital industry, with large equipment cost. Factory owners have extended their production chain yearly, so that their depreciation is displayed increasingly. The result is that the cost of TFT-LCD is increasing, and the cost structure of it is different yearly. Like 15″ TFT-LCDs for example. The depreciation/production cost is 10.1% in 2000, 12.1% in 2001 and 13.8% in 2003. The direct materials/production cost is 45.4% in 2000, 55.0% in 2001 and 53.3% in 2002 (see Table 5).

	2000	2001	2002
Depreciation/production cost	10.1%	12.1%	13.8%
Direct materials/production cost	53.3%	55.0%	53.3%
Direct salary/production cost	3.9%	3.5%	3.1%
Other payment/production cost	40.6%	29.4%	29.8%

Table 5: Cost structure of large-size TFT-LCD

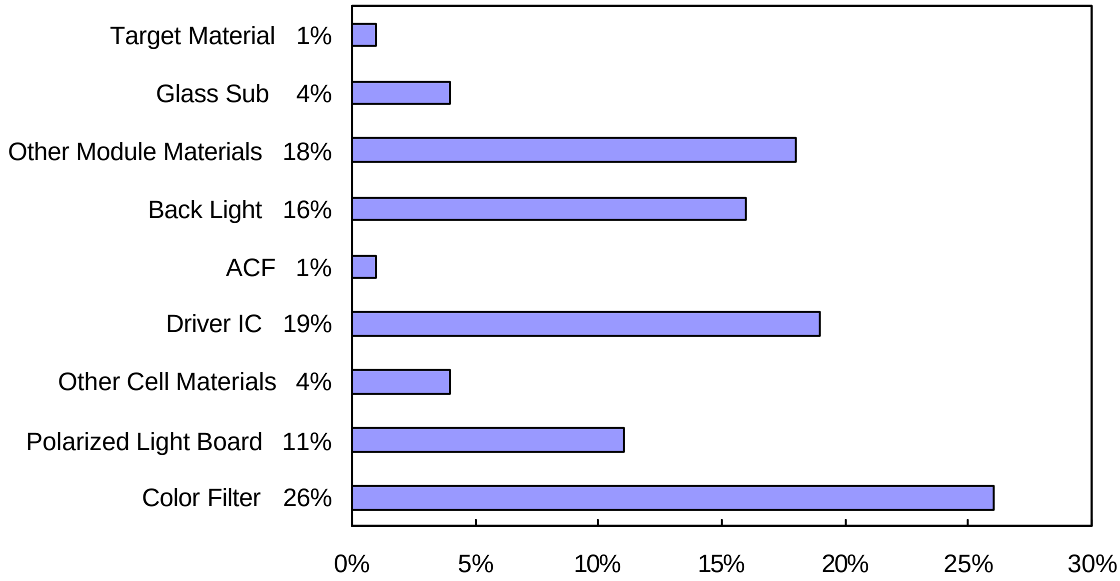
Among them, direct materials cost is the highest. According to ITIS 2001 research, the cost of Color Filter (CF) is about 26% of the direct material cost, being the highest. Drive IC is about 19%, being the second, and the third is Black Light at about 16% ext. (see Figure 2).

3.3. Downstream industries

In the domestic market, the manufacturers which use large-size TFT-LCDs key in on LCD monitors, notebook monitors and LCD TVs. In other words, large-size TFT-LCDs are mainly used in these three manufactures above. As in 2002 for example, LCD monitors took up about 66.27% of TFT-LCD production, and the weight of notebook monitors used are 33.7%, LCD TVs are 0.03%. Among them, LCD monitors are continuously replacing traditional CRT monitors, even-though the price of LCD monitors are still high, say at 66.27% of 2003 to 70.01% of 2003 (see table 6). Again LCD TVs also increased.

As we have related above that key domestic TFT-LCDs are in 15 inches, and among 15-inch TFT-LCDs' main applications are for LCD monitors. Hence we would

Figure 2. 15 inches TFT-LCD Direct Material Cost Structure



Source : SiJin Wang(2003) got from Sintok Optoelectronics

see that 15-inch LCD monitors are the main products of the TFT-LCD industry (see table.6). Furthermore, due to 70%-80% of cost of LCD monitor is upon TFT-LCD, hence the ex-supplies of TFT-LCD of the present year made display price drop and indirectly made either CRT monitors or 14-inch LCD monitors replaced by LCD monitors. The development of 15-inch TFT-LCDs also promote the development of NB market, hence attacking the production of 15-inch LCD monitors as a result. It forced LCD monitor manufacturers to promote 15 inches to 17 inches since 2001.

	2002	2003
LCD monitors	66.27%	70.01%
Notebook monitors	33.70%	27.79%
LCD TV	0.03%	2.20%

Table 6: Taiwan's large-size TFT-LCD downstream manufactures' share

Source: MIC and TIE

Among each size of LCD-monitors, smaller than 15 inches are principally for NB computers, do not interest consumer anymore in the near future, and the quantity of output is decreasing. 18- and 19-inch LCD-monitors may be the most attractive sizes, but the high price makes it one of the upper-goods, and it has not prevailed so far. As for sizes larger than 20 inches, it depends on the specific use. As the price of 17-inchdecreases, 17-inch LCD monitors have become the main size in the market.

<table>
<tr><th></th><th>1998</th><th>1999</th><th>2000</th><th>2001</th><th>2002</th><th>2003</th></tr>
<tr><td><14 inches</td><td>48.7%</td><td>30.6%</td><td>17.23%</td><td>4.04%</td><td>2.07%</td><td>1.10%</td></tr>
<tr><td>15 inches</td><td>51.3%</td><td>68.3%</td><td>80.00%</td><td>81.13%</td><td>72.48%</td><td>55.00%</td></tr>
<tr><td>17 inches</td><td rowspan="4">0%</td><td rowspan="4">1.1%</td><td>0.32%</td><td>11.88%</td><td>19.685</td><td>34.80%</td></tr>
<tr><td>18 inches</td><td rowspan="3">2.45%</td><td>2.55%</td><td>3.685</td><td>3.70%</td></tr>
<tr><td>19 inches</td><td>0.05%</td><td>1.35%</td><td>4.10%</td></tr>
<tr><td>> 20 inches</td><td>0.35%</td><td>0.74%</td><td>1.30%</td></tr>
</table>

Table.7: Domestic LCD monitor manufactured structure

Source: MIC

Now, Taiwan's main LCD-monitors manufacturers include BenQ, Sampo, CTX Opto-Electronics, Jean, Tatung, Compal, Lite-On Electronics, Pro-Arch Technology, Delta Electronics and Amtran Technology.

4. Efficiency measurement

The efficiency measurement is an important course for the science of management, and it is the center of cost controlling for the manufacturing industry. An effective efficiency measurement approach can help the department to raise the resource for effective input and output.

Efficiency or productivity analyses are vital managerial control tools for assessing the degree to which inputs are utilized in the process of obtaining desired outputs (Golany and Roll, 1989).

Fielding (1987) had divided the definition of the performance into cost efficiency, service effectiveness and cost effectiveness. Cost efficiency analyzes the relationship between the input and products, service effectiveness analyzes the relationship of the products and consumers; to stress on the server's exploitative extent that the consumers use. Cost effectiveness analyzes the relationship between the inputs and consumers; to stress on the factored input's exploitative extent that the consumers use. The relation are displayed as the following Figure 3.

In general, we can express the measure of productivity into a single mathematical approach: $productivity = output / input$. In this, if we use the value as units then the equation must be measurement of efficiency. If we use the quantity as the units, then it will become the measurement of productivity.

The concepts of productivity and performance are considered to encompass efficiency and effectiveness. An efficient indicator should measure the degree to which resources have been used economically, and hence should be $input / output$ or $output / input$ ratio. An effectiveness indicator should measure the extent to which an objective has been achieved. In other words, efficiency is "doing things right" and effectiveness is "doing the right thing". However, both efficiency and effectiveness measures are considered to measure productivity, since the terms "productivity", "efficiency" and "effectiveness" have been used synonymously (Gleason and Barnum, 1982).

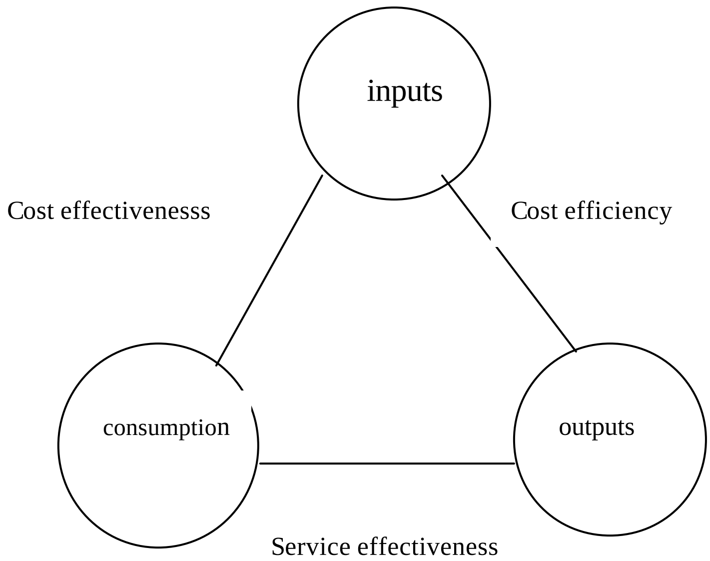


Figure 3: Concept of performance by Fielding

Charnes et al.(1978) had interpreted the efficiency by Input-Orientation and Output-Orientation;

Input-orientation: if an organization can produce the same amount of output with less of input factors and not more for any other input, then this organization is inefficient.

Output-orientation: if an organization can produce more amount of output with the same amount of input factors, then this organization is inefficient.

In general, the efficiency measurements include (1) Ratio Analysis Approach. (2) Balanced Scorecard Approach (3) Total Factor Productivity (TFP) (4) Regression Analysis Approach (RA) (5) Production Frontier Approach (PFA) (6) Stochastic Frontier Approach (SFA) (7) Multi-Criteria Decision Making (MCDM) (8) Data Envelopment Analysis Approach (DEA).

Among them, the measurement of manufacturing industry's efficiency, defined as "productivity measurement" includes (1) Total factor productivity (2) Regression approach (3) Production frontier approach (4) Stochastic frontier approach (SFA) and (5) Data envelopment analysis, as shown in Table 8.:

Table 8: Non-DEA methods advantage and disadvantage

Approach	Advantage	Disadvantage	Issue
TFP	Simple Can be used as the aggregative indicator of measuring an enterprise's productivity Impersonal result	Can't exhibit the better effective value Can't separate the technical improvement or technical efficiency Need to set the weight of input	Parkan and Wu (1999). Ext.
RA	Regression basis	Can't solve multiple input and multiple output problems at the same time Must assume the residual to be of normal distribution Output items must have detailed data	Griliches and Regev (1995)
PFA	Simple Lesser limit	Have to consider probabilitydistribution The residuals must assume to be of normal distribution	Wu (2000)
SFA	The result is close to the real condition	Have to consider probabilitydistribution Needs a lot of observed elements in order to get the exact research value	Kumbhakar et al. (1997)

The traditional literature on productivity measurement tackling "efficiency measurement" from various points of view, applying different approaches, like "economic approach", "productivity approach" and "engineering approach", are not satisfactory for measuring productivity in the service and public sectors or in non-profit organizations, since some of the factors are not readily expressed in economic terms. The main reasons for the failure of traditional productivity measurement approach are (1) these are based on "process measures", with little attention on "outcome measures". (2) Such outcome of measure is usually extremely difficult to assign proper relative weights. (3) It is very difficult to formulate an explicit functional relationship between inputs and outputs, with fixed weights on the various factors. (4) Averaging many Decision Making Units (DMUs) fails to explain the behaviors of individual DMUs (Golany and Roll, 1989).

5. Efficiency measurement Using DEA

5.1. DEA Method

DEA is based on the economics concept of Pareto-optimality, which states that a given decision making unit is underperforming if some other DMU, or some combination of DMUs can achieve at least the same amounts of all outputs with less resource input and not any more of any other resource. Data envelopment analysis approach which is used as product frontier to form the basis of efficiency measures, and obtain the value of produce frontier by mathematic model, does not need to pre-assume any production function model. We can obtain product frontier by substituting targets' input and output value into mathematical models, then comparing each individual DMU's actual observed value and product frontier The difference illustrates relative-efficiency or relative-inefficient of individual DMU.

The original DEA must retrace to the issue, titled "The Measurement of Productive Efficiency", edited by Farrell (1957). Farrell applied Production Frontier, and ensured Deterministic Non-Parametric Efficiency Frontier formulated with mathematical programming approach, to measure efficiency. Farrell had divided efficiency into Technical Efficiency (TE), meaning "given constant input factor, the ability to produce maximum output, given constant output operating with the least input excesses", Allocation Efficiency (AE), means "the assessment of efficiency value using given relative price of cost-function", and Overall Efficiency (OE), obtained from TE into AE.

Charnes et al (1978) throughout Ratio Measure approach generalized Farrell's measure of single output efficiency into multiple-output, and named it "Data Envelopment Analysis (DEA)". It defined the performance Frontier, a geometrical frontier, with the most possible output of various inputs combination, and represents the targets' input and output into geometrical forms. If located onto the Efficiency Frontier, and established it to be the most-efficiency, efficient-index is 1. If not, offer it an indicator, which is larger than 0 and smaller than 1, and measure its relative efficiency with the difference of DMU and Efficiency Frontier.

The DEA is based upon the economic notion of Pareto optimality, which states that a given DMU, or some combination of DMUs, is inefficient if some other DMU can produce at least the same amounts of all output with less of some resource input and not more of any other resource (Lewin et al, 1982).

As time went by, DEA eventually developed. For example, DEA had been under the assumption of constant return to scale, till Banker et al. (1984) released the assumption of constant return to scale into variable return to scale, hence TE could be divided into Pure-Technical Efficiency and Scale efficiency, and can measure the scale efficiency of organizations' DMU. Charnes et al. (1985) had introduced additional approach of DEA. Charnes et al (1985) had applied sensitive analysis of DEA, et cetera. (see Seiford,1996)

After Charnes et al. (1978) applied DEA conception in their literature, DEA became a technical efficiency measure tool for either public or private organizations (Lewin, 1995). DEA yields managerial information not only in respect to individual units but also to units at the collective level. Peer units which a DEA assessment identifies efficient can be used to highlight the weak part of the performance of the corresponding inefficient unit (Boussofiane et al, 1991).

Chang (1998) had used the DEA model to analyze the efficiency of six Taiwan central government-owned hospitals in 1990-1994, and then used multiple regression methods to analyze the efficiency score got from DEA. Avkiran (2001) used the DEA model to compare the relative efficiency of Australian universities based on 1995 data. Three performance are developed, namely, overall performance, delivery of educational services' performance and fee-paying enrolment's performance.

These were some articles which use DEA to measure performance of manufacturers, like Thompson et al. (1996) focusing on the analysis of efficiency and productivity of US' 14 oil companies for the years 1980-1991, and comparing the extremely efficient companies by the result of the DEA approach and Maximum Profit Ratio approach. Thore et al. (1996) measured the efficiency of 44 US computer companies during 1981-1990, to confirm the key relationship between efficiency and the product cycle. Yunos and Hawdon (1997) analyzed 27 electricity utilities/companies in developing countries with GDP per capita in the region of US$1500-2800 for 1987, to compare the performance of Malaysia's National Electricity Board with those of countries.

Generally, DEA has the following advantage and disadvantage points. (Lewin and Minton, 1986).

Advantages:

(1) Able to analyze the relatively most effective organizations in comparison to relatively least effective organizations.

(2) Capable of deriving a single summary measurement of relative effectiveness of organizations in terms of their utilization of resources and environmental factors to produce desired outcomes.

(3) Able to handle multiple inputs and outputs.

(4) Able to handle qualitative factors such as participant satisfaction, extent of information processing available, and degree of competition.

(5) DEA does not require the assumption of any pre-specified functional form of the production function, and can avoid the problem of parameter measures.

(6) The weights of inputs and outputs are derived from linear programming, and not dependent on subjectivity.

(7) Efficiency scores of DEA models are relative efficiency indices, and able to analyze using insights unit factors, and

(8) Able to maintain equity in the evaluation.

Disadvantage:

(1) Due to being a non-random approach, wrong input and putout data would result in divergent efficiency scores.

(2) Data of DMUs must be homogeneous in order to obtain effective efficiency scores.

(3) The efficiency scores are relatively efficient, not absolute, and unable to compute the effective input and output quantity.

(4) The numbers of DMUs have to be greater than two times the sum of dependent and independent variables.

However, the conventional DEA models merely focus on the measurement of productive efficiency in a single-stage operation; that is, a cross-sectional analysis for the whole production chain of the industry. At next section I would like to introduce the articles that had introduced Two-stage DEA models.

5.2. Extent of DEA

Castelli et al. (2001) introduced a DEA model, which relaxed the assumption of homogeneous DMU, to assess the efficiency of interdependent sub-units within a larger DMU with the sense that part of the output of one unit may be the input of the others. Sexton and Lewis (2004) used this knowledge to described two-stage DEA model, with output of the first stage becoming the input of the second stage. Furthermore, they established separate efficient frontiers for Stage 1 and Stage 2. The advantages of two-stage DEA model over single stage DEA model is that it can distinguish whether inefficiency occurs on the first or second stage. Sexton and Lewis (2004) used this idea to formulation Two-Stage DEA Model to measure Major League Baseball efficiency. He divided baseball teams' DMU into two sub-DMUs, formed from the teams' managers looking for talents and score as the first stage, and the teams' score that won the game as the second stage. As shown in the Figure 4., he defined Total Player Salaries (TPS) as the input of the first-stage, Total Bases Gained (TBG) and Total Bases Surrendered (TBS) to be intermediate products, which mean the output of the first stage and input of the second stage. Games Won (GW) is to be the output of the second stage. The model distinguishes inefficiency in the first stage form that in the second stage, allowing managers to target inefficient stages of the production process.

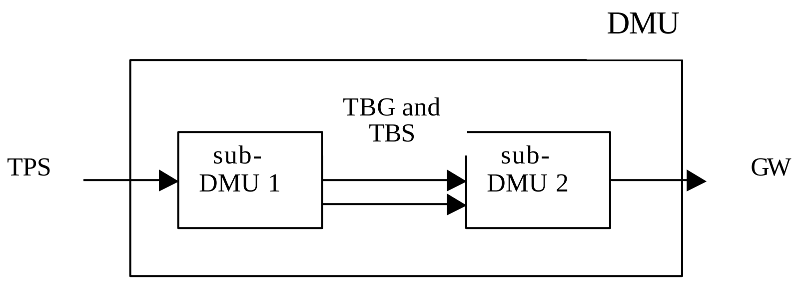
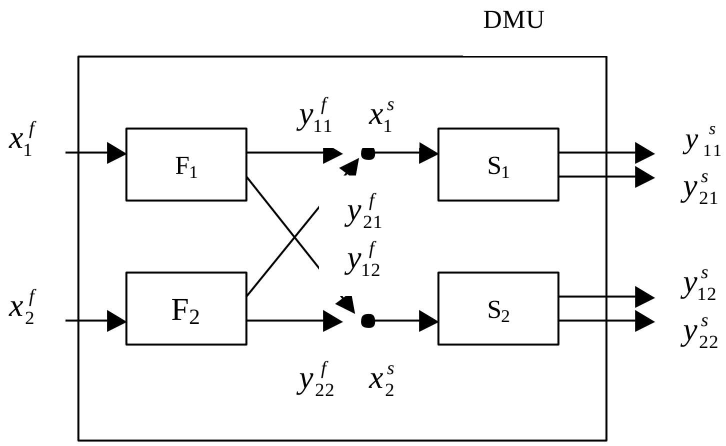


Figure 4: Thomas model each DMU as two sub-DMUs connected in series.

Unlike Sexton (2004) one sub-DMUs' series, one-input and one output, Lorenzo et al. (2004) introduced "DEA-like models for the efficiency evaluation of hierarchically structured units", though also conferred internal structure of DMUs as the former, the latter measures performance of organization by considering multiple input and multiple output as shown in Figure 5. Figure 5 shows a simple two-layer structured DMU. Each layer is composed of two sub-units and each sub-unit has a single input and two outputs. There are three assumptions:

(1) Only two stage structures are considered.
(2) Each sub-DMU has only single inputs, the single input flow used by a subunit of the second level may come from different sub-units of the first level.
(3) All the sub-units belonging to the same layer have the same number of outputs.



Fiure.5: Two-layer structured DMU

Denote U to be the set of existing homogeneous DMUs under evaluation, while $u \in U$ refers to the generic DMU. And F and S as the set of all the sub-DMUs of the first and second stage, $f \in F$ and $s \in S$ refer to the generic sub-DMUs. $F(u) \subset F$ and $S(u) \subset S$ as the sets of the sub-DMUs belonging to the same DMU u $\forall u \subset U$. The outputs yielded by sub-DMU f feed the unique sub-unit of the second stage. Under these hypotheses, the maximum relative efficiency of first stage of DMU u_0 may be evaluated as:

$$q_f(u_0) = \sup_{v_f w_f} \frac{\sum_{f\in F(u_0)} \sum_{s\in S(u_0)} w_{\hat{s}f}\, y_{\hat{s}f}}{\sum_{f\in F(u_0)} v_f x_f},$$

$$s.t \quad \sum_{f\in F(u_0)} \sum_{s\in S(u)} w_{\hat{s}f}\, b_{fu} y_{\hat{s}f} - \sum_{f\in F(u)} v_f\, b_{fu} x_f \le 0 \qquad (1)$$

$$\forall u \in \hat{U}, \quad \forall f \in F, \quad \forall s \in S, \quad \forall b_u \ge 0,$$

$$V_f, W_f > 0$$

where,

$q_f(u_0)$ = is the maximum relative efficiency of the first stage of DMU u_0

x_f = is the level of input used by sub-DMU f.

$y_{\hat{s}f}$ = is the level of output yielded by sub-DMU f and the input of the second sub-DMU $\hat{s}$.

v_f = is the vector of the weights for the input flow of the generic sub-DMU f.

w_f = is the vector of the weights for the output flow from the sub-DMU f.

b_u = is the associated vector of the feasible non-negative constants scaled by the same factor of the inputs and the outputs of each sub-DMU.

The maximum relative efficiency of second stage of DMU u_0 may be evaluated as:

$$q_s(u_0) = \sup_{v_s w_s} \frac{\sum_{s\in \hat{S}(u_0)} \sum_{k=1}^{K_s} w_{k\hat{s}}\, y_{ks}}{\sum_{s\in S(u_0)} v_{\hat{s}} x_s},$$

$$s.t \quad \sum_{s\in S(u)} \sum_{k=1}^{K_s} w_{k\hat{s}}\, b_{su} y_{ks} - \sum_{s\in S(u)} v_{\hat{s}}\, b_{su} x_s \le 0 \qquad (2)$$

$$\forall u \in \hat{U}, \quad \forall \hat{s} \in \hat{S}, \quad \forall b_u \ge 0,$$

$$V_s, W_s > 0, \quad k = 1,\ldots, K_s$$

where,

$q_s(u_0)$ = is the maximum relative efficiency of the second stage of DMU u_0

x_s = is the level of the input used by sub-DMU s.

y_{ks} = is the level of the output k yielded by sub-DMU $\hat{s}$.

v_s = is the vector of the weights for the input flow of the generic sub-DMU s.

$w_{k\hat{s}}$ = is the vector of the weights for the output flow k coming from the sub-DMU $\hat{s}$.

b_u = is the associated vector of the feasible non-negative constants scaled by the same factor the inputs and the outputs of each sub-DMU.

Assuming that each output is the virtual weight of the sub-DMU of the first stage and is equal to the output virtual weight of the sub-DMU of the second stage .

$$v_{\hat{s}} b_{su} x_s - \sum_{f \in F(u)} w_{\hat{s}f} b_{fu} y_{\hat{s}f} = 0$$

The efficiency value evaluated as the product of the maximum relative efficiencies of each single stage:

$$q(u_0) = q_f q_s$$

$$= \sup_{V_f, W_f, V_s, W_s} \frac{\sum_{f \in F(u_0)} \sum_{s \in S(u_0)} w_{\hat{s}f} y_{\hat{s}f}}{\sum_{f \in F(u_0)} v_f x_f} \frac{\sum_{s \in S(u_0)} \sum_{k=1}^{K_s} w_{k\hat{s}} y_{ks}}{\sum_{s \in S(u_0)} v_{\hat{s}} x_s} \quad (3)$$

$$= \sup_{V_f, W_f, V_s, W_s} \frac{\sum_{s \in S(u_0)} \sum_{k=1}^{K_s} w_{k\hat{s}} y_{ks}}{\sum_{f \in F(u_0)} v_f x_f}$$

$$s.t. \quad \sum_{s \in S(u)} \sum_{k=1}^{K_s} w_{k\hat{s}} b_{su} y_{ks} - \sum_{f \in F(u)} v_{\hat{f}} b_{fu} x_f \le 0$$

$$\forall u \in \hat{U}, \quad \forall b_u \ge 0,$$

$$v_{\hat{s}} b_{su} x_s - \sum_{f \in F(u)} w_{\hat{s}f} b_{fu} y_{\hat{s}f} = 0$$

$$\forall u \in \hat{U}, \quad \forall s \in S(u), \quad \forall b_u \ge 0,$$

$$V_f, W_f, V_s, W_s > 0$$

$q(u_0)$ = is the maximum relative efficiency of DMU u_0, and the others are defined as above.

However, that's just the two-stage DEA model's internal structure analysis of single stage's decision making units. In fact, this model is merely dismantling single-stage DMU into two-stage DMUs and measures the efficiency of single stage of organizations. We would not know if the inefficiency was due to other streams of the manufacturers.

In this paper, I would like to use the idea of two-stage DEA to measure the performance of manufacturing industries. Consider an extension of the DEA model in which we model each DMU as two sub-DMUs connected in series. In other words, I will combine two DMUs into one DMU. Hence each DMU acts as a sub-DMU in the new DMU combination

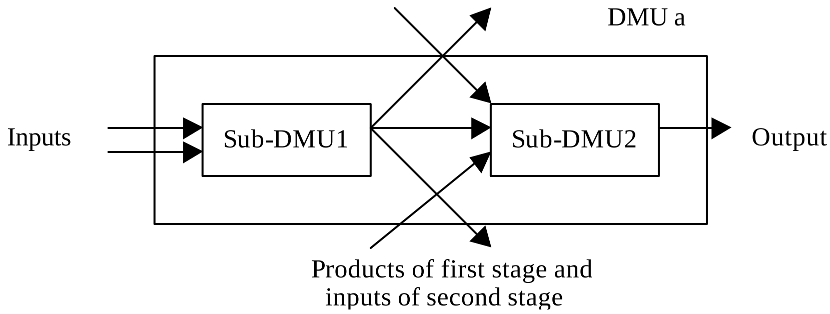


Figure 6: Two-stage structure DMU

Fig. 6 shows two-stage structured DMUs. Consider the simplest situation, in which DMUs represent production chain of industries. In each DMU, a part of the output of the first stage sub-DMUs becomes a part of input of the second stage sub-DMUs, known as intermediate products. In the simple assumption of the DEA model, the maximum relative efficiency of a stage 1 sub-DMU formulates as follow:

$$Max q_f = \sup_{b_f a_f} \frac{\sum_{k=1}^{K_f} a_{kf} y_{kf}}{\sum_{p=1}^{P} b_{pf} x_{pf}} \tag{4}$$

subject to $\sum_{k=1}^{K_f} a_{kf} y_{kf} - \sum_{p=1}^{P} b_{pf} x_{pf} \leq 0$

$a_{kf} \geq 0, \quad b_{pf} \geq 0$

$f = 1,\ldots,F$
$k = 1,\ldots,K$
$p = 1,\ldots,P$

where, x_{pf} = is the level of input p consumed by sub-DMU f

y_{kf} = is the level of output k produced by sub-DMU f

$f \in F = F$ is the set of sub-DMUs of the first stage

b_{pf} = is the weight placed on the input p consumed by sub-DMU f

a_{kf} = is the weight placed on the output k produced by sub-DMU f

The maximum relative efficiency of a stage 2 sub-DMU formulates as follow:

$$Max q_s = \sup_{a_s b_s} \frac{\sum_{i=1}^{I_s} a_{is} z_{is}}{\sum_{j=1}^{J} b_{js} w_{js}} \tag{5}$$

subject to $\sum_{i=1}^{I_s} a_{is} z_{is} - \sum_{j=1}^{J} b_{js} w_{js} \leq 0$

$a_{is} \geq 0, \quad b_{js} \geq 0$

$s = 1, \ldots, S$
$i = 1, \ldots, I$
$j = 1, \ldots, J$

where w_{js} = is the level of input j consumed by sub-DMU s

z_{is} = is the level of output i produced by sub-DMU s

$s \in S = S$ is the set of sub-DMUs of the second stage

b_{js} = is the weight placed on the input j consumed by sub-DMU s

a_{is} = is the weight placed on the output i produced by sub-DMU s

The efficiency value evaluated as the product of the maximum relative efficiencies of each single stage:

$$\begin{aligned} q(u_0) &= q_f q_s \\ &= \sup_{a_f, b_f, a_s, b_s} \frac{\sum_{k=1}^{K} a_{kf} y_{kf}}{\sum_{p=1}^{P} b_{pf} x_{pf}} \frac{\sum_{i=1}^{I} a_{is} z_{is}}{\sum_{j=1}^{J} b_{js} w_{js}} \end{aligned} \tag{6}$$

subject to

$\sum_{k=1}^{K_f} a_{kf} y_{kf} - \sum_{p=1}^{P} b_{pf} x_{pf} \leq 0$

$\sum_{i=1}^{I} a_{is} z_{is} - \sum_{j=1}^{J} b_{js} w_{js} \leq 0$

$\forall u \in U$

$a_{kf} \geq 0, \quad b_{pf} \geq 0, \quad a_{is} \geq 0, \quad b_{js} \geq 0$

$$f = 1,\dots,F \qquad s = 1,\dots,S$$
$$k = 1,\dots,K \qquad i = 1,\dots,I$$
$$p = 1,\dots,P \qquad j = 1,\dots,J$$

Where u_0 represented a production chain in the industry. Furthermore, unlike Castelli et al. (2004) who separated a DMU from internal structure, hence the output of first stage must be equal to the input of second stage, i.e. $\sum_{f \in F(u_0)} \sum_{s \in S(u_0)} w_{\hat{s}f} y_{\hat{s}f} - \sum_{s \in S(u_0)} v_{\hat{s}} x_{\hat{s}} = 0$

They may not be equal in my equation, since these is the absence of intermediate products between them. The second stage may not consume all of the first stage outputs, similarly its input factors may not all be first stage outputs, especially in manufacturing industries.

5.3. Numerical Data

This article considers a set of four Taiwan large-size TFT-LCD manufacturers (AUO, CPT, HANNSTAR, CME), denoted as A, B, C and D. as the first stage sub-DMUs of LCD industry production chain during 2001~2003[2], the upstream manufacturers of the industry which we are analyzing. The second stage considers a set of nine Taiwan LCD monitor manufacturers (BenQ, Sampo, CTX, Jean, Tatung, Compal, Lite-on, Pro-Arch, Delta), denoted as a, b, c, d, e, f, g, h and i, the downstream manufacturers of the production chain[3]. As a result we will analysis ten production chains.

5.4. Variable selection

As for the establishment of input and output items, coordinating the input and output items used in past issues, we can see that in analyzing different types of target we choose different sets of items. Generally speaking, analyzing the manufacturing industry we used to choose the following items as our input and output items;

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[2] Even though there are five manufacturers, one of them, we denote as E, totally exports its products abroad, hence I excluded it.

[3] There are ten manufacturers in Taiwan, one of which, denoted as j is eliminated because its displays are imported entirely.

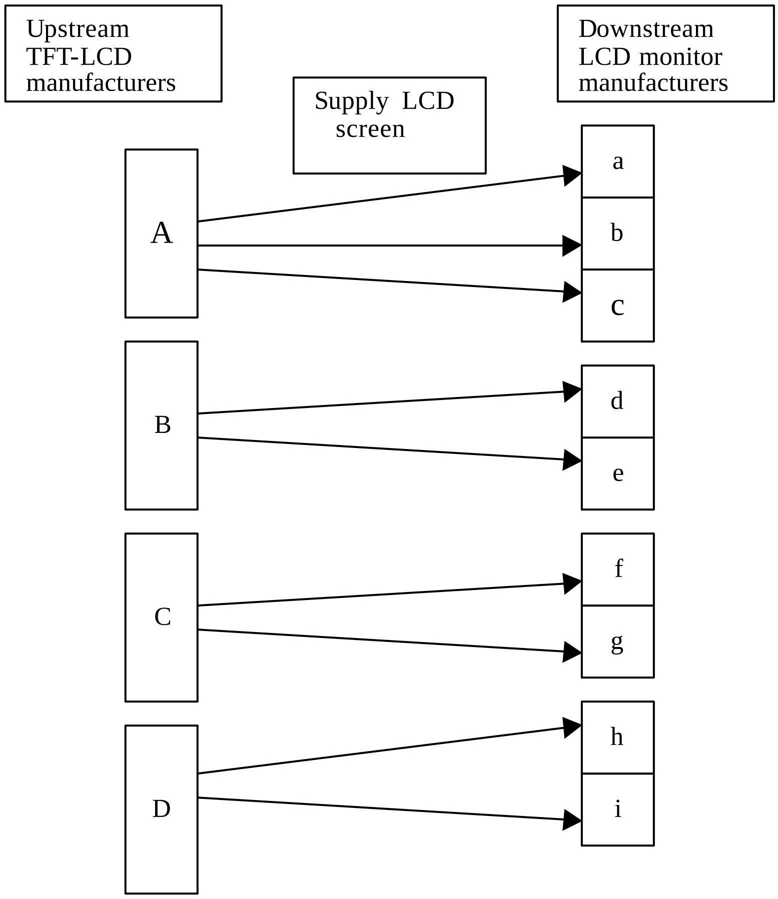


Figure.7: Domestic TFT-LCD production chains

Variable number	Definition
Input items	
Fixed asset (x_1, w_1 : thousand NT dollars)	Includes plant, land, building, furniture, rental machines and other properties
Number of employees (x_2, w_2 : people)	Number of direct and indirect employees of the current financial year
Output items	
Revenue (y, z : thousand NT dollars)	Selling income

Table.9: Input and output items in analysis in this issue.

This issue gathers the manufacturers' data that this article analyzes from the

Taiwan Economics Journal (TEJ). Since this research is at the point of productivity of manufacturing factory, so I selected two suitable input items and one output item as shows in Table 9.

We will separately find the relative efficiency value of these nine production chains, five TFT-LCD manufacturers and ten LCD monitor manufacturers with DEAP Version 2.1, a software of finding efficiency measurement. Firsty, I would like to find the Technical Efficiency (TE) of all-over manufacturers by using CCR approach. Hence I am able to analyze which of them are efficient or inefficient. Again find the Pure Technical Efficiency (PTE) by using the BCC method, and divide the TE with PTE, we will get the Scale Efficiency (SE). Analyzing their PTE and SE allows us to know that the inefficiency of manufacturers are due to the inefficiency of PTE or SE.

Finally I would like to find their Malmquist Productivity Index, as established by Fare, Grosskopf, Lindgren and Ross (1989). It is a kind of measurement of the relativity of technology and Total Factor Productivity (TFP) of a DMU of various periods. In other words, Malmquist Productivity Index is the measurement of the change of productivity during periods.

6. Research result

In Table 10 we see the Overall Efficiency of the four TFT-LCD manufacturers during 2001~2003.

DMU	2001	2002	2003	Mean	Sequence of efficiency value	Sequence of capital
A	0.673	1.000	1.000	0.891	1	1
B	1.000	0.623	0.362	0.662	3	3
C	0.509	0.640	0.177	0.442	4	4
D	1.000	0.376	1.000	0.792	2	2
Mean	0.795	0.660	0.635	0.697		

Table 10: OE value of TFT-LCD manufacturers

In Table 11 we see the Overall Efficiency of the nine LCD monitor manufacturers during 2001~2003.

DMU	2001	2002	2003	Mean	Sequence of efficiency value	Sequence of capital
a	0.428	1.000	0.215	0.548	2	3
b	0.289	0.350	0.108	0.249	7	7
c	0.605	0.339	0.036	0.327	6	6
d	0.074	0.051	0.027	0.051	9	8
e	0.989	0.253	0.179	0.474	3	2
f	1.000	1.000	1.000	1.000	1	1
g	0.216	0.200	0.206	0.207	8	4
h	0.043	0.938	0.093	0.358	5	9
i	0.274	1.000	0.093	0.455	4	5
Mean	0.435	0.570	0.217	0.407		

Table 11: OE value of LCD monitor manufacturers

In these tables above, we will find that none of the TFT-LCD manufacturers achieved perfect efficiency (i.e., $OE = 1$) in average of three years. Fortunately their means is relatively higher (about 0.697). As for LCD monitor manufacturers, there is also no perfect efficiency except f firm, whose mean is generally lower (about 0.407). If we look at their data, the invest scale of f was the largest, with advantage that its input selling expense was 5 times larger than d, and revenue is 7 times. When upstream and downstream trades with each other, their efficiency sequence changes, and the means of efficiency value becomes 0.487. Firms which achieve perfect efficiency appear on the production chains $B-d$, it means that when they traded they became efficient.

In table 12 we see the Overall Efficiency of the nine TFT-LCD production chains during 2001~2003.

DMU	2001	2002	2003	Mean	Sequence of efficiency value	Sequence of combination capital
A-a	0.204	0.414	0.513	0.377	6	1
A-b	0.517	0.670	0.583	0.590	3	6
A-c	0.195	0.221	0.207	0.208	7	5
B-d	1.000	1.000	1.000	1.000	1	9
B-e	0.148	0.116	0.307	0.190	8	4
C-f	0.385	0.588	0.625	0.533	4	2
C-g	0.624	0.179	0.462	0.422	5	3
D-h	0.757	0.853	1.000	0.870	2	8
D-i	0.126	0.206	0.195	0.176	9	7
Mean	0.444	0.472	0.544	0.487		

Table 12: production chains' OE value

Among them, B has the obvious relative disadvantage on fixed assets between TFT-LCD firms, and d has the obvious relative advantage on fixed assets but has relative disadvantage on human resource. When d *and* e were evaluated together with B, it seem that the disadvantage of B was filled up by the advantage of d. Again, e has disadvantage in its fixed assets, so it might not be filled up by B. Hence, when B trades with both d *and* e, production chain $B-d$ has higher efficiency value, while production chain $B-e$ has lower efficiency value.

D has the disadvantage in fixed assets and advantage in human resource, so was complement with h which has the opposite advantage. The opposite situation occurs on production chain $D-i$, for the reason that they have the same disadvantage on fixed assets, and their efficiency is down. In production chain $C-f$, C has the advantage on fixed asset, disadvantage on labor resource, while f has the best situation on both resource. The result is that firm C was pulling down the production chain. As for g, it has advantage on human resource and disadvantage in fixed asset, and they complete each other.

If we notice the relationship of the capital and efficiency value, both in TFT-LCD industries and LCD-monitor industries, expect g *and* h, the sequence of efficiency value is sorted in the series as the sequence of their capital - the larger capital, the higher efficiency value. But is opposite on production chains, the larger capital, the lower efficiency value. It might be due to the fact that larger capital wastes resource more.

As we explained above, the inefficiency of OE may be due to either the inefficiency of PTE or SE. In fact, there are three situations for inefficiency of firms. The first is that the inefficiency is because of the inefficiency of PTE while its SE is in perfect efficiency. The other situation is that the inefficiency is due to the inefficiency of SE while its PTE is perfectly efficient. The last situation is that the inefficiency comes from both PTE and SE.

Table 13 shows PTE and SE of TFT-LCD firms during 2001~2003:

DMU	2001		2002		2003	
	PTE	SE	PTE	SE	PTE	SE
A	1.000	0.673	1.000	1.000	1.000	1.000
B	1.000	1.000	0.828	0.753	0.598	0.605
C	1.000	0.509	1.000	0.640	0.490	0.362
D	1.000	1.000	0.500	0.753	1.000	1.000
Mean	1.000	0.795	0.832	0.786	0.772	0.742
Std. Dev						

Table 13: PTE and SE value of TFT-LCD firms' PTE and SE value

Since OE is the multiple of PTE and SE, it means that the inefficiency of OE is due to the PTE or SE, or may be both of them or may be one of them. If its PTE is inefficient, that means administration is not managed well, hence wasting resource. If its SE is inefficient, it means an Increase Return to Scale (IRS) or Decrease Return to Scale (DRS).

Table 14 shows PTE and SE of LCD monitors firms during 2001~2003:

DMU	2001		2002		2003	
	PTE	SE	PTE	SE	PTE	SE
A	0.491	0.872	1.000	1.000	0.262	0.820
B	1.000	0.289	0.555	0.630	0.783	0.138
C	1.000	0.605	0.420	0.806	0.130	0.274
D	0.435	0.169	0.399	0.127	0.191	0.143
E	1.000	0.989	0.290	0.873	0.290	0.618
F	1.000	1.000	1.000	1.000	1.000	1.000
G	0.499	0.482	0.277	0.722	0.264	0.782
H	0.487	0.089	1.000	0.938	1.000	0.093
I	0.579	0.472	1.000	1.000	0.216	0.428
Mean	0.716	0.552	0.660	0.788	0.459	0.477

Table 14: PTE and SE value of LCD monitors firms

Table 15 shows PTE and SE of production chains during 2001~2003:

DMU	2001		2002		2003	
	PTE	SE	PTE	SE	PTE	SE
A-a	1.000	0.240	1.000	0.414	1.000	0.513
A-b	1.000	0.517	1.000	0.670	0.901	0.647
A-c	0.318	0.614	0.346	0.639	0.347	0.597
B-d	1.000	1.000	1.000	1.000	1.000	1.000
B-e	1.000	0.148	0.280	0.414	0.574	0.536
C-f	1.000	0.385	1.000	0.588	1.000	0.625
C-G	0.930	0.671	0.354	0.505	0.828	0.559
D-h	1.000	0.757	1.000	0.853	1.000	1.000
D-I	0.182	0.693	0.323	0.638	0.369	0.529
Mean	0.826	0.558	0.700	0.636	0.780	0.667

Table 15: shows production chain' PTE and SE value

For example in the production chain $D-h$. If we observe TFT-LCD firm D, we will find that it has an efficiency value of 1.000 in 2001, 0.376 in 2002 and 0.792 in 2003. When we observe its PTE and SE in 2001, it has 1.000 and 1.000, in 2002 it has 0.500 and 0.753 and in 2003 it has 1.000 and 1.000. Hence the inefficiency of 2002 is due to both PTE and SE, the other years are both efficient in both PTE and SE, especially PTE.

When we observe LCD monitor firm h, we will find that it has efficiency value of 0.043 in 2001, 0.938 in 2002 and 0.093 in 2003. If we observe its PTE and SE, in 2001 it has 0.487 and 0.089, in 2002 it has 1.000 and 0.938, in 2003 it has 1.000 and 0.093. Hence we can say that its inefficiency is due to the inefficiency of SE.

Again if we look at production chain $D-h$. We would see that either its PTE or SE became almost perfectly efficient. It means that when we evaluate its production chain efficiency, its efficiency rises. It might be the reason that the inefficiency of D's PTE was completed by i's PTE, and the inefficiency of i's SE was completed by D's SE.

When we observe LCD monitor firm i, we will find that it has efficiency value of 0.274 in 2001, 1.000 in 2002 and 0.093 in 2003. If we observe its PTE and SE, in 2001 it has 0.579 and 0.472, in 2002 it has 1.000 and 1.000, in 2003 it has 0.216 and 0.428. Hence we can say that its inefficiency is due to the inefficiency of PTE.

Again if we look at production chain $D-i$, we would see that its OE efficiency value 0.126 in 2001, 0.206 in 2002 and 0.195 in 2003. The efficiency values of PTE and SE in 2001 are 0.182 and 0.693, in 2002 they were 0.323 and 0.638, in 2003 they were 0.369 and 0.529. We will find that its efficiency value was decreasing. The reason might be that both inefficiencies are PTE related, so when they traded, an exclusive situation occurred. The same situation occurred in production chain $C-f$, $C-g$.

Table 16 shows SE and Return to Scale (RS) of TFT-LCD firms:

DMU	2001		2002		2003	
	SE	RS	SE	RS	SE	RS
A	0.673	DRS	1.000	CRS	1.000	CRS
B	1.000	CRS	0.753	IRS	0.605	IRS
C	0.509	IRS	0.640	IRS	0.362	IRS
D	1.000	CRS	0.753	IRS	1.000	CRS

Mean	0.795		0.786		0.742	

Table 16: SE and return to scale of TFT-LCD firms

Table 17 shows SE and Return to Scale (RS) of LCD monitors firms:

DMU	2001		2002		2003	
	SE	RS	SE	RS	SE	RS
a	0.872	IRS	1.000	CRS	0.820	IRS
b	0.289	IRS	0.630	IRS	0.138	IRS
c	0.605	IRS	0.806	IRS	0.274	IRS
d	0.169	IRS	0.127	IRS	0.143	IRS
e	0.989	IRS	0.873	IRS	0.618	IRS
f	1.000	CRS	1.000	CRS	1.000	CRS
g	0.482	IRS	0.722	IRS	0.782	IRS
h	0.089	IRS	0.938	IRS	0.093	IRS
i	0.472	IRS	1.000	CRS	0.428	IRS
Mean	0.552		0.788		0.477	
Std. Dev						

Table 17: SE and RS of LCD monitors firms

Table 18 shows SE and Return to Scale (RS) of production chains:

DMU	2001		2002		2003	
	SE	RS	SE	RS	SE	RS
A-a	0.240	DRS	0.414	DRS	0.513	DRS
A-b	0.517	DRS	0.670	DRS	0.647	DRS
A-c	0.614	DRS	0.639	DRS	0.597	DRS
B-d	1.000	CRS	1.000	CRS	1.000	CRS
B-e	0.148	DRS	0.414	DRS	0.536	DRS
C-f	0.385	DRS	0.588	DRS	0.625	DRS
C-G	0.671	DRS	0.505	DRS	0.559	DRS
D-h	0.757	IRS	0.853	IRS	1.000	CRS
D-i	0.693	DRS	0.638	DRS	0.529	DRS
Mean	0.558		0.636		0.667	

Table 18: SE and RS of production chains

As shown in Table 16, 17 and 18, all of TFT-LCD firms and LCD-monitor firms are in increase return to scale or constant return to scale, except in 2001 for A. When they traded, all of their RE of production chains decreased return to scale except production chain $B-d$ which is in constant return to scale and production chain $D-h$ which increased return to scale.

Figure 8: relative input resource of TFT-LCD firms

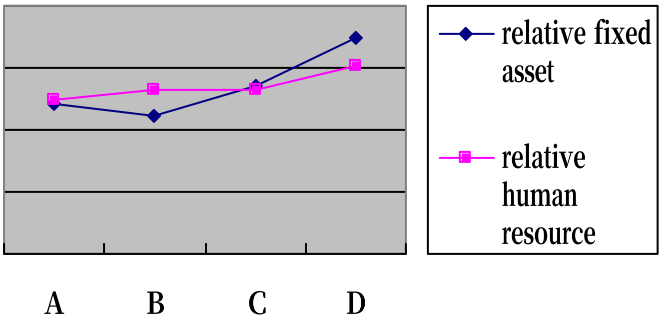
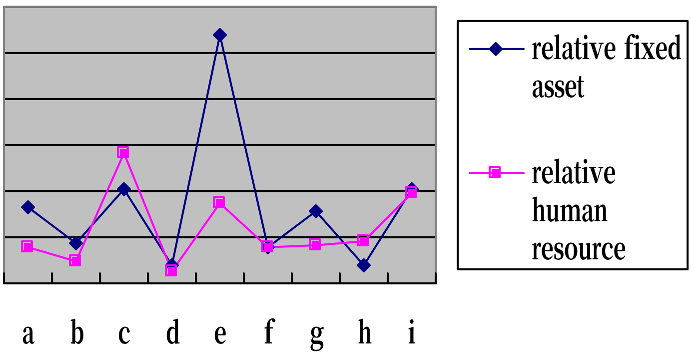


Figure 9: relative input resource of LCD-monitor firms



These IRS firms can rise up their output to maximize their revenues by increasing their inefficiency factor input. For example, TFT-LCD firm D, whose inefficient part is PTE. Its fixed asset was relatively too large, so it should increase human resource to increase output[4]. LCD-monitor firm h is inefficient in SE. Its human input is relatively too large, so it should increase fixed assets to increase output. Hence when they traded, they filled up each other.

Again LCD monitor firm i was inefficient in PTE. Its fixed asset was relatively

[4] See figure 8 and figure 9.

too large, so it should increase its human resource to increase output, and when it traded with D, production chain $D-i$ the fixed asset seemed relative larger and made its efficient value fall.

7. Conclusion

This issue is a research on Taiwan's TFT-LCD industry's vertical trade, and efficiency measurement of TFT-LCD manufacturers for upstream and LCD monitors manufacturers for downstream,. Since the TFT-LCD industry is a new technical industry, with the first firm established and mass produced in domestic was in May 1999, and the latest in 2001. The domestic LCD monitors industry's input materials' LCD screen, are gotten most from domestic TFT-LCD manufacturers. That's why I have to use the 2001~2003 data.

In order to compare the vertical trade of which production chain is more efficient, we used DEA model and DEAP version 2.1 to run the result, and we found:

(1) Most of the Taiwan's TFT-LCD firms and LCD monitor firms are in increase of return to scale, and they can raise their input factors to increase their revenue.[5]

(2) When we consider the efficiency of the manufacturers, their upstream (downstream) firms influence its efficiency much. If they have the same inefficient (efficient) parts, an exclusive situation will occur in their trade.[6] If they have the different inefficient (efficient) parts, a complemental situation will occur in their trade [7].

(3) If they are complementary in operational situation, its efficiency will increase, if exclusive in operation situation, its efficiency will decrease.

(4) They should better trade with who has the opposite situation to raise their revenue, or change their input structure.

(5) No matter what situation they have, complement or exclusive, the production chain which they organized show a decrease return to scale except $B-d$ and $D-h$, for the reason that such combination lacked of sieving, and was not as suitable as effective.

(6) In Taiwan TFT-LCD and LCD monitors firms, the efficiency seems to depend on their capital, the larger the capital, the higher efficiency value, TFT-LCD~LCD monitor production chains do not.

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[5] If their PTE is inefficient, and their fixed asset is too high, they should better raise their human resource, or raise their fixed assets.

[6] Both of them have higher fixed assets or human resource.

[7] See figure 8 and figure 9.

According to the result above, when TFT-LCD firms and LCD-monitor firms trade with each other, the managers may not have considered the suitability or not. Maybe they merely thought about self-profit, not the efficiency of production chains. One day they integrated their upstream (downstream), so they would need this approach.

In this paper we used two-stage DEA approach, say, Hierarchical DEA-like model to analyze the interval structure of a DMU of manufacturing production chain. Before, scholars used two-stage DEA approach to analyze interval structure of a DMU of non-profit organizations. The paper shows that the knowledge of the combination of two DMUs into one can be used to evaluate the relative efficiency of industries. It seems to work in the analysis of profit organizations or manufacturing industries. In the future, people can use this two-stage DEA method to analyze other profit organizations, i.e., financial industry, and further, in three stages.

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