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The Accumulated Resources Model of Industry Development - a Case Study in Taiwan

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Abstract

The display industry has followed the semiconductor industry to become an important high-tech industry. In 2015, the total production value of Taiwanese large-sized TFT-LCD was US$19,423.21 million, which makes Taiwan the second world leader in TFT-LCD production. In fact, the development of the Taiwanese TFT-LCD industry is a dynamically accumulated resource process with many causative variables that helped form a complex and developed industrial system. This study applies system dynamics to model the developmental structure of the large-sized TFT-LCD industry in Taiwan. The results of this study show that the three largest internal factors: accumulated R&D talent, capital, and technology levels required for this industry. However, external factors such as industry attractiveness, large-sized TFT-LCD technology transfer from Japan, and government policies play significant roles. Finally, we discuss the simulation results for the development trend of large-sized TFT-LCD industry in Taiwan.

Keywords: the display industry; the semiconductor industry; the high-tech industry; large-sized TFT-LCD; system dynamics

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1. Introduction

The high-tech industry is a capital-intensive, technology-intensive, high-risk, and high-return industry that has been nurtured by many Newly Industrialized Countries (NICs). Thus, the creation of successful development experiences and models has become an important issue. The display industry has followed the semiconductor industry to become an important high-tech industry. For the whole display industry, whether in terms of production value or production capacity, the Thin Film Transistor Liquid Crystal Display (TFT-LCD) industry constitutes the greatest proportion. The production value of large-sized TFT-LCD constitutes the majority of global LCD industry production value, making up almost 70% of total LCD production value. As for the Taiwanese LCD industry, Jing Ye Electronics and Hughes Aircraft of the US cooperated to start the first TN production line in 1976. Development of large-sized TFT-LCD, however, stagnated until the late 1990's. At that time, Japanese manufacturers were affected by a domestic economic recession. In addition, due to price competition pressure from South Korean manufacturers, Japanese manufacturers began cooperating with Taiwanese manufacturers. As a result, many Taiwanese companies began constructing and expanding LCD production lines. Through technical cooperation with Japanese manufacturers, production yield rates of Taiwanese manufacturers quickly reached mass production levels and Taiwan was able to compete with Japan and South Korea in the global market.

However, by 1997, the production value of LCD reached US$467.90 million. In 2015, the total production value of Taiwanese large-sized TFT-LCD was US$19,423.21 million, which makes Taiwan the second world leader in TFT-LCD production. It is also representative for the first time that a single industry in Taiwan has exceeded 1 trillion TWD in production value (Liu, 2009). In fact, the development of the TFT-LCD industry is dynamic and sophisticated and is characterized by a series of continuous interactions and evolutions that involve industrial development systems along with its external environment. The development of that large-sized TFT-LCD industry in Taiwan has been intimately related with the mutual drive and impact of other factors, such as research and development (R&D) talent, accumulated capital, technology levels, industry attractiveness, large-sized TFT-LCD technology transfer from Japan, and government policies. Therefore, it requires an overall perspective from a comprehensive study to understand the large-sized TFT-LCD industry development system in Taiwan.

System dynamics (SD) maintains that the behavior of a system is principally caused by the systems structure (Forrester, 1961; Roberts, 1978). Uncovering the structure of a complex system requires mastery of concepts such as feedback, stocks, flows, time delays, and non-linearity (Sterman, 2000). The SD approach is an effective means of handling the interactions of the key players in a specified system (Ford, 1997; Pardue et al., 1998; Dangerfield, 1999; Jan & Hsiao, 2004; Chen & Jan, 2005; Jan & Chen, 2005) and its application areas: strategic decision-making level and analyses, high level perspectives as well as qualitative analysis (Bayer & Gann, 2007; Jahangirian et al., 2010; Hsiao, 2014).

This study applies system dynamics to model the developmental structure of the large-sized TFT-LCD industry in Taiwan to examine its system behavior. First, we analyzed the characteristics of the large-sized TFT-LCD industry and its interaction with the socioeconomic environment of Taiwan, deriving a qualitative model in accordance with the identified structure. Next, we derived and simulated a quantitative model in a historical setting. Third, we simulated the model in one possible scenario to test the impact. Finally, we

discuss the simulation results for the development trend of large-sized TFT-LCD industry in Taiwan.

2. Characteristics of the TFT-LCD Industry

The imaging of liquid crystal display (LCD) is through the combination of pixels of different brightness and colors on the panel. The intensity and color of the light source is determined and is applied to the liquid crystal molecules. Liquid crystal molecules are organic and have the optical properties of solid crystals as well as the fluidity of liquids. By changing the voltage of the Driver IC, the arrangement of the liquid crystal molecules shifts according to the direction of the electric field. Thus, refraction angle is altered and the intended image is produced.

Due to the features of thinness, lightweightness, small volume, energy efficiency, and low voltage and radiation, LCDs are widely used in many types of display equipment and have gradually replaced CRT displays in the market. Of the different LCD products, thin film transistor liquid crystal (TFT-LCD) are the mainstream of LCD flat-panel displays (FPD) because of their high resolution, contrast, and response speed, and the fact they have the most mature manufacturing process.

"Liquid Crystal" refers to crystal substances in a liquid state. The American RCA company first used “liquid crystal” in the display panel of an instrument in 1968. The Japanese Sharp Corporation later transferred the patent for LCD technology from RCA and successfully developed calculators, wristwatches, and instrument panels using LCD panels in 1973. Thus, this was the formal beginning of the era for application and commercial value of LCD products (Wang, 2003).

2.1 General Characteristics of the TFT-LCD Industry

The rapid growth of the LCD Industry has gained attention for replacing the Cathode Ray Tube (CRT) market for such products as personal computers, TVs, and handsets due to its thin, light and low power-consuming features (Yoon & Park, 2005) and for developing its own innate market for such products as notebook computer screens, automobile guidance systems, video cameras, and DVD screens. These are all new markets that combine optics and communications technologies (Chen, 2006). The typical characteristics of TFT-LCDs are as follows.

2.1.1 Capital-intensive industry: high barriers to entry and exit for companies

2.1.2 Technology-intensive industry with patent rights protection

2.1.3 Rapid replacement speed of product production technologies

2.1.4 Large fluctuations in product prices are easily affected by business cycles

2.1.5 Spread of international horizontal outsourcing

2.2 Additional Characteristics for Taiwanese Large-sized TFT-LCD Industry

The LCD industry in Taiwan began in 1980 with Jing Ye Electronics. The American company Hughes Aircraft introduced TN-LCD technology, which constituted the earliest technology import and original equipment manufacturing (OEM) in Taiwan. Thereafter, Chunghwa Picture Tubes introduced large-sized TFT-LCD production lines from Mitsubishi

ADI, a Japanese firm. Thereby, Taiwan formally entered the field of large dimension TFT-LCD panels. The unique characteristics that allowed the large-sized TFT-LCD industry in Taiwan to become the world leader in only 30 years are outlined below.

2.2.1 Support from government policies and R&D systems

Industrial Technology Research Institute of Taiwan (ITRI), which has played a significant role in technological and talents development for Taiwanese high-tech industries, began R&D for LCDs between 1987 and 1988 with technological evaluations of high-temperature polysilicons and noncrystal silicon. The "Microelectronic Technology Development Plan" included budgets, machine purchases and R&D between 1989 and 1992. The "Flat Panel Display Technology Development 4-year Plan" from 1993 to 1997 and the "Flat Panel Display Key Technology Development 6-year Plan" from 1997 to 2003 were intended to establish industry technologies through R&D cooperation with the industry. The plans described above resulted in transferring many technologies to the domestic industry. However, for the industry, ITRI encouraged "R&D" technologies rather than mass production technologies.

2.2.2 Support from talents of the semiconductor industry and personal computer assembly industry

The primary production process of TFT-LCD can be divided into three main portions: TFT fabrication, LC assembly, and module assembly process (Jeong et al., 2002). In the past, there were few engineers in Taiwan with experience in TFT-LCD mass production. The development of the Taiwanese semiconductor industry over the past 30 years has allowed Taiwan to acquire knowledge in precision equipment, developing technology talents, and related silicon wafer fabrication facility management; these aspects are closely related to the first stage of TFT production (Chen & Jan, 2005). Particularly worthy of note is Japanese and South Korean manufacturers were nearly all involved in the semiconductor industry. In contrast, there were few companies in the Taiwanese TFT-LCD industry that had crossed over from the semiconductor industry and had converted internal company resources. Only AU Optronics and HannStar were able to obtain early stage array production technologies and operation resources from semiconductor-related companies. Most other companies in the industry had allocated human resources from other industries (Wang, 2003). End-stage production processes were supported by the abundant talents with assembly experience accumulated from the industries of personal computer assembly and assembly of other information peripherals. Technological talents for LC assembly were the most lacking; this area became a focus of technology transfer from Japanese companies to the Taiwanese LCD industry.

2.2.3 Domestic downstream market driving – notebook computer industry

Taiwan is the largest base for outsourced production of information technology products such as personal computers, notebook computers, and monitors. The high degree of development in the personal computer outsourced assembly industry has allowed Taiwan to gain great experience in the global logistics management of upstream components and complete financial planning; this experience is inextricably tied to TFT end-stage module production. As Taiwanese companies have an extremely high proportion of market share for information and communication product production outsourcing on the world market, display components, which are essential to cost structure, became an industry that needed to be actively grasped by companies in effective cost-lowering strategies. In addition to

considerations of the application potential of the industry in the future market, Taiwanese companies actively invested in the TFT-LCD industry field because Taiwan is an important globally exporter of notebook computers. LCD panels make up nearly 30% of the total cost of notebook computers; possessing a self-owned panel supply system is very beneficial to the reduction of notebook computer costs and stability of panel supply.

2.2.4 Parent Factories Supply Technology

By 1991, two TFT-LCD companies had been established in Taiwan. However, these companies operated on a small scale due to an inability to break Japan's technological barrier, which prevented them from developing their own industry. After being affected by the Asian financial crisis in 1997, the economic situation in Japan worsened; at the same time, Japanese companies also faced pricing pressure from South Korean companies. In order to overcome the difficulties and increase competitiveness, Japanese companies released technologies to Taiwanese companies and obtain profits from technology transfer fees(Chen, 2003). Since 1998, 6 Taiwanese companies (Unipac Optoelectronics Corp., Chunghwa Picture Tubes Ltd., Chi Mei Optoelectronics, Acer Display Technology, Inc., HannStar Display Corp., and Quanta Display Inc.) have become involved in TFT-LCD production and have driven large investment in upstream supporting components, causing Taiwan to become a major outsourcing center for Japanese TFT-LCD companies.

2.2.5 Dependency on Japan for import of primary materials

In the production cost structure of TFT-LCD, the proportion of material costs is as high as 50%, a situation substantially different than in semiconductor production, in which production costs stem from machinery and equipment costs (Huang, 2005). Currently, aside from primary materials, which are limited to the primary source country of Japan, most other key upstream components such as color filters, driver IC, backlight modules, and polarizers
can be produced by Taiwanese TFT-LCD companies themselves.

The display industry has followed the semiconductor industry in becoming an important high-tech industry in the world. The LCD industry is sometimes termed the "second semiconductor industry". Jeong et al. (2002) presents development of an available-to-promise system for TFT-LCD manufacturing in global supply chain environment. Hung (2006) explored the competitive strategies of TFT-LCD industry in Taiwan, specifically the national system of innovation. Su et al. (2006) first conducted field survey on the supply chain of TFT LCD industry, and analyzes the manufacturing process of glass substrate, which is a key material of TFT-LCD. Park et al. (2008) implied that a spillover effect from high technology firms diversifies their products from existing technological capabilities. Yun et al. (2010) investigates cluster formation and the development processes of new TFT-LCD clusters in East Asia. Hsiao et al. (2011) employed a four-role framework and evolution model to investigate the industrial development of TFT-LCD industry in Taiwan. Hsiao et al. (2014) collected to model the existing industrial product demands and greenhouse gas emissions data for the Taiwan TFT-LCD industry. Liao & Kuo (2014) investigated the relationships among collaborative supply chain value innovation, supply chain capabilities, and firm performance by examining a case of the TFT-LCD industry in Taiwan. Tsui & Wen (2014) is to develop a green supplier selection procedure for the TFT-LCD industry using polarizer suppliers as an example.

The literature reviews of TFT-LCD industry are described as above. There are many research methods, for example, an available-to-promise (ATP) system (Jeong et al., 2002), a

postponement strategy (Su et al., 2006), a heuristic approach with transfer function model (Lin et al., 2006), descriptive statistics (Stolpe, 2002), grey forecasting (Chang, 2005), a data envelopment analysis (DEA), an analytic hierarchy process (AHP), and a fuzzy multicriteria decision-making approach (Tseng, 2007), applied on the TFT-LCD industry However, there has been little literature to discuss the system structure of Taiwanese large-sized TFT-LCD industry development from a macro perspective in order to understand system behavior and fulfill system management purpose. In fact, the development of an industrial system is a complex and dynamics process. SD is an appropriate methodology to study the development of industrial system. Analyzing each key player's policies makes it possible to construct information-decision-action loops that allow us to understand the system's structure and behavior.

3. Methodology

System Dynamics (SD), proposed by Jay W. Forrester in 1956, is a methodology for understanding certain kinds of complex problems. It began as "Industry Dynamics", focusing on problems arising in the corporate setting. SD methodology is often used to solve systematic problems with multiple causations that interact with one another. This is done by finding key causations and sensitive variables to interpret the effects of variables or external environments on the system (Coyle, 1996). SD is widely applied in advanced and long-term strategy-making studies. It was first used in industrial dynamics (Forrester, 1961) and then in urban dynamics (Forrester, 1969). SD was later adapted into systematic learning and social science (Senge, 1990). Since industry development is a long-term and dynamic process, it is a suitable research target for SD (Ford, 1997).

Andrew Ford (1997) implemented SD approach contributed to useful change in the electric power industry. Pardue et al. (1998) argues that classical technology diffusion modeling approaches fail to give a fully dynamic picture of technology adoption in an industry. Jan & Jan (2000) applies the SD methodology to construct a weapon systems development model for Taiwan. Jan & Hsiao (2004) researched in the development of the automotive industry and explore the system behavior using SD methodology. Chen & Jan
(2005) analyzed the development experience of the Taiwanese semiconductor industry, in order to provide better insight into the long-term industrial development process. Lee & Tunzelmann (2005) attempted to develop a mathematical model using SD of the national innovation system (NIS) of Taiwan, particularly with regard to its integrated circuit (IC) industry.

Dattee & Weil (2007) showed the dynamics of social factors during technological substitutions have significant effects on substitution patterns. Lee et al. (2011) found that the level of technology has a non-monotonic effect on technology-improving investments with intermediate investors more apt to invest in catch-up. Hsiao et al. (2011) proposed a causative relationship model for the large-sized TFT-LCD industry in Taiwan. Although qualitative models are useful to describe the importance of TFT-LCD industry development, these models do not comprehensively describe the dynamic interaction between industry and environment. Consequently, previous studies have not revealed the underlying structure of
successful development experiences in Taiwan.

4. Modeling

The development of TFT-LCD industry depends on the accumulation of development resources (Hsiao et al., 2011). This study analyzed the development resources according to

R&D talent, accumulated capital and technology levels, and then used system dynamics methodology to construct a causative relationship model for the Taiwanese large-sized TFT-LCD industry development.

4.1 Causal Feedback Loop of Research and Development Talents

The primary R&D talent sources needed in the development of the TFT-LCD industry in Taiwan include high technology talents from ITRI (Taiwan) (Mathews & Cho, 2000; Liu & Stars, 2000), from three Japanese companies in Taiwan: Hitachi in Kaohsiung, Sharp Taiwan, and Epson Taiwan, from the semiconductor industry, and from an advanced domestic education system. Government policies that encourage industry-university cooperation have caused technical institutions to understand the needs of industry. Graduates with higher education have become the backbone of human resources for industry in Taiwan.

Figure 1 depicts the causal loop of R&D talent. The high profitability of the industry has attracted talent and increases the overall number of R&D talent. Training programs conducted by the government included the early "Flat Panel Display Technology Development 4-year Plan" from 1993 to 1997 that featured human resource investment of up to 600 individuals; and the "Flat Panel Display Key Technology Development 6-year Plan" conducted from 1997 to 2003, with an investment in over 200 individuals. Increases in training programs conducted by the government has caused funding for training R&D talent to increase by attracting talent and increase the size of the talent pool. Further, leading to increases in R&D costs as well as over costs and has become a factor in decreasing profits. When profits decrease, the attractiveness for TFT-LCD talent also decreases. This, in turn, causes a negative feedback loop.

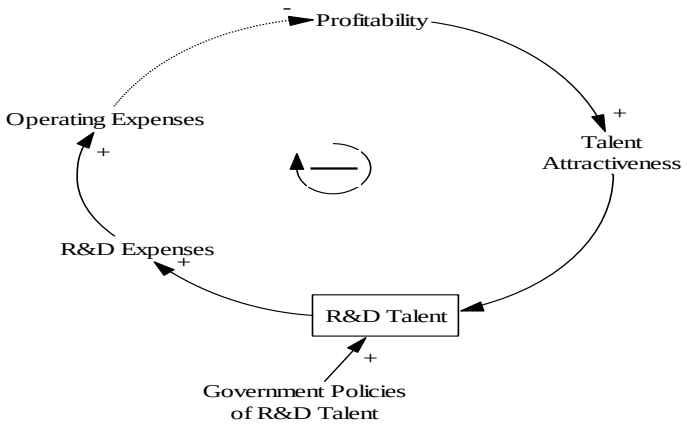

Fig. 1: Causal feedback loop of research and development talent

4.2 Causal Feedback Loop of Accumulated Capital

The ROC government has provided many positive policies to incentivize participation in the LCD industry in two directions. The first was the government provision for industry members with financial channels, such as the 1991 "High-tech Type 3 Stock Market Listing Law" to assist industry members to raise capital. The second was the government policy for tax incentives that exempted the TFT-LCD industry. Thereby, an increase in the annual returns by reducing or completely exempting industry members from the profit-seeking enterprise income tax. These policies were beneficial to industry financing and tax exemptions.

In addition to surplus earnings accumulated from profits, sources of increased capital include requesting increased funding from investors, internal investment or borrowing from external sources, external investment. By increasing internal investment, companies issue normal stock or preferred stock for investors. By increasing external investment, they also issue depository receipts, such as American Depository Receipts (ADR), to apply for market-listed transactions in the American region to attain funding from local investors and for the sake of future ADR circulation and transactions. In terms of borrowing from external sources, companies issue commercial paper to raise capital for short-term financial use. For long-term funding, companies issue company bonds, including general corporate bonds or convertible corporate bonds to attain funding from unspecified investors. Alternatively, companies arrange for long-term loans from financial institutions. Capital investment in the panel industry was vast and leads the industry being referred to as the "money-burning profession". In particular, the scale of investment for the next generation only increased. The industry may be even more reliant on market funding plans in the future.

In 2001, the ROC governments opening policy towards China began by allowing Notebook (NB) industry members to establish and invest in Mainland factories. To members of the TFT-LCD industry, performing module assembly abroad was one of the most effective methods of reducing production costs. Nine years later, the ROC government further liberalized policies regarding LC assembly technology transfer to Mainland China. Sixth-generation and older TFT-LCD panel plants have no limits, while sixth-generation and newer TFT-LCD panel plants proposing Mainland investment must have a technology gap of more than one generation compared to panel plants located in Taiwan.

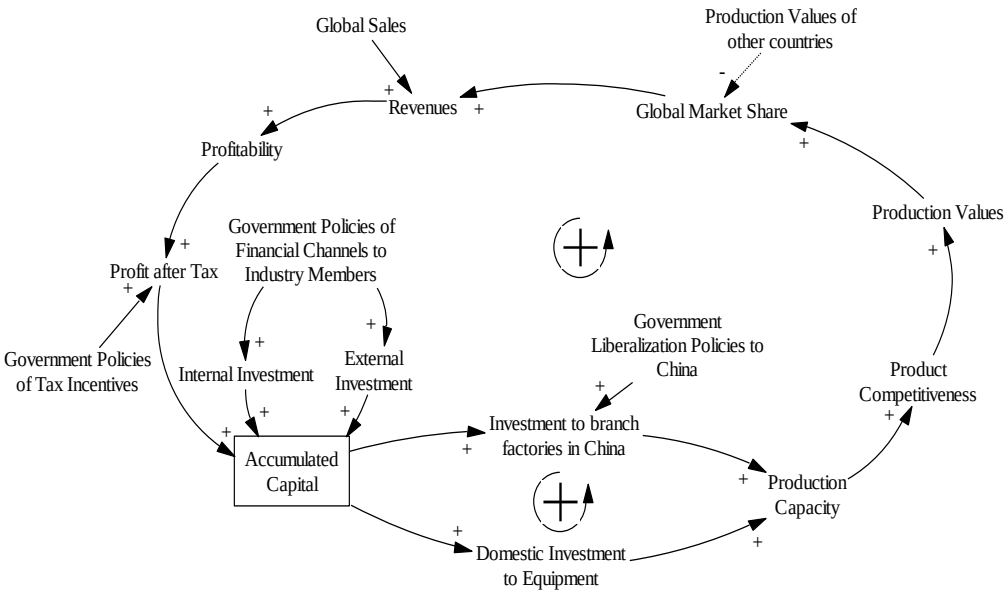

Fig. 2: Causal feedback loop of accumulated capital

Figure 2 depicts the causal feedback loop of accumulated capital. When profitability is high, the accumulation of capital increases along with the willingness of stockholders to invest in next-generation technologies. Thus, the investment in equipment increases. Concurrently, due to the liberalization policies of the government towards China, industry members invest in Mainland factories to achieve effective reduction of production

costs and increases in production capacity. This further improves product competitiveness, which leads to an increase in production values and, therefore, an increase in the global market share. A high global market share increases the revenues and profitability of industry members to ultimately form two positive causal feedback loops.

4.3 Causal Feedback Loop of Technology Levels

The rapid growth and successive technological innovation of industries provide more opportunities for latecomers to enter promising markets and to become competitive players (Yun et al., 2010). Due to the financial crisis of 1997, Japanese industry members released existing production technologies to Taiwan to earn technology premiums. This injected cash into enterprise units. Meanwhile, the ROC government actively formulated various policies that encouraged industry members to perform in-house R&D, such as the 1987 "strategic industry appropriate range", the 1991 "Law Encouraging Private Development of New Products", "Key Component Development Methods", and "Microelectronic Technology Development Plan" between 1989 and 1992. More recently, the government instituted the "Flat Panel Display Technology Development 4-year Plan" from 1993 to 1997, the "Flat Panel Display Key Technology Development 6-year Plan" from 1997 to 2003, and the "Two Trillion, Two Stars" industry strategy of the "2008: National Focus Development Plan" from 2002 to 2007. The aim of the above-listed projects was to establish industry technology through joint R&D to allow Taiwan companies to quickly enter the field of large-sized TFT-LCDs. The technology level of industry members has continually trailed those of South Korea and Japan by a margin of approximately 2.5 generations. Increase in profitability attracts R&D talent to invest in this industry. R&D talent requires a certain amount of time for experience to accumulate (delay mark, requires the accumulation for a time) to improve technology levels. With simultaneous research subsidy policies, technology transfers from Japan, and investment in industry R&D expenses ( ) to improve technology levels, the increase of technology levels further improved manufacturing yields. In turn, this further reduces unit production costs, increases profitability, and forms a positive causal feedback loop. However, the increase of R&D talent, increases in R&D expenses, and subsequent increases in operating expenses contribute toward decreasing profitability to form a negative causal feedback loop, as shown on Figure3.

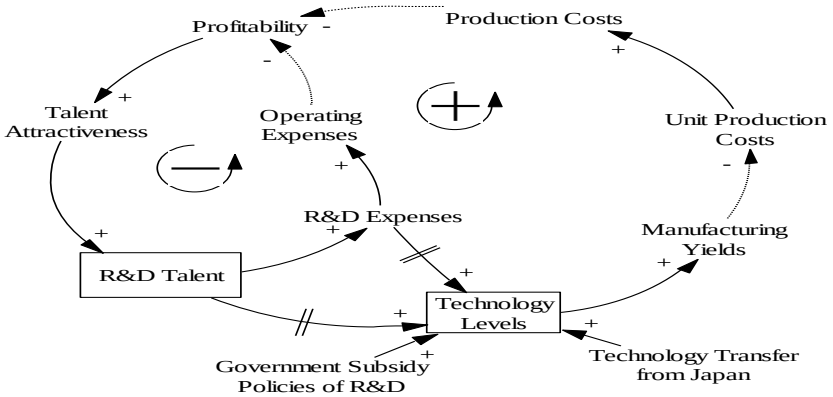

Fig. 3: Causal feedback loop for technology levels

4.4 Quantitative Model

The quantified data in this study was based on the annual reports of AU Optronics

Corporation from 1999 to 2009 and the Flat Panel Display Industry Yearbook from 2002 to 2010. AU Optronics annual reports' data was converted to the overall data of Taiwanese large-sized TFT-LCD industry. AUO's large-sized and small and mid-sized production value ratio was roughly 90%: 10%. AU Optronics's market share of large-sized TFT-LCD was 17% of the global market, and Taiwanese large-sized TFT-LCD had a 42% market share of this global market. The information contains industry data over a span of near 30 years, from 1997 to 2024. In 1997, due to the Asian financial crisis, Japan transferred its large-sized TFT-LCD technology to Taiwan. The data extends to the year 2024 because during interviews in 2009, AU Optronics experts expressed their belief that the TFT LCD industry was mature and should still have another 10-15 years as the mainstream. The quantified model exchange rate used was based on Customs announced average buy rate of USD: TWD = 1: 32.50 from January 1, 1997 to April 30, 2010. Currency units of the system were in USD million, and the production units were in thousands pieces. This study established a quantified model that included three stocks and 42 equations, using Vensim 5.8 computer software. The variables and their relationships in the three stocks were explained below.

4.4.1 R&D Talent

The primary production process for TFT-LCDs is divided into three main sections: TFT array production, LC cell assembly, and LCD panel module assembly. For a production line TFT-LCD capable of producing 60,000 pieces of glass substrate in a month, the array and cell sections are the more challenging processes. The array section needs 20-30 engineers on average and the cell section needs 10 engineers on average. The LCM section is labor intensive and needs 50 people or more on average. Currently, most array and cell sections are located in Taiwan. After, 2001, the Taiwan government opened up outsourcing and investment to China. As a result, more than 90% of LCM sections are now completed in China. Industries, which gain profits, attract human resources. Since the manufacturing process of arrays and semiconductors is similar, talent from the semiconductor and Japanese LCD panels were drawn in the early stages. After 2000, the R&D talents mostly come from domestic graduate schools of science and engineering and are developed by governmental training policies for R&D talent.

R&D talent that entered the large-sized TFT-LCD industry included science graduates from seven universities: National Taiwan University, National Tsing Hua University, National Chiao Tung University, National Cheng Kung University, National Central University, National Sun Yat-Sen University, and National Yang-Ming University. Graduates begin to add value after they have worked in the TFT-LCD industry for six months and are able to become independent R&D staff in two to three years. Consequently, the development of human resources slightly lags. Government policies promoting development of R&D talent has included the "Flat Panel Display Technology Development 4-year Plan" from 1993 to 1997 (600 people), and the "Flat Panel Display Key Technology Development 6-year Plan" from 1997 to 2003 (200 people). The flow rate of TFT-LCD industry R&D talent was about 8%. The equation descriptions of related variables for R&D talent are as follows. Figure 4 is a dynamic diagram of R&D talent.

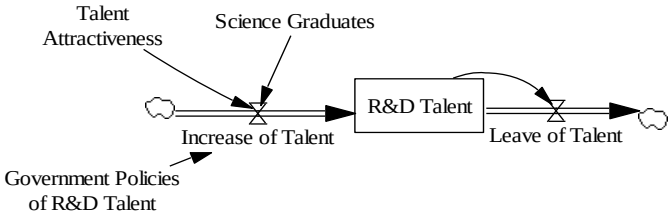

Fig. 4: Dynamic Diagram of R&D Talent

4.4.2 Total Assets

Operating gain (loss) was one of the numerous indices used to evaluate corporate management performance. It indicated the performance of corporations and was the primary profit index. Aside from normal operations, there were also many nonoperational activities such as investment in securities that utilized idle money, the issuing of bonds to expand production facilities and to pay off interest, and profits/losses generated from hedging. All of these factors generate non operating objects. Government rewards policies towards investments also influenced the corporate decision-making and investment returns. In addition, policies such as the profit-seeking enterprise income tax rate also affected company investment willingness and net income.

Total assets were primarily formed by the accumulation of net income, external investment, and internal investment. Stockholder investment in the company, or share capital, was called internal investment. When net income was generated through corporate operations, stockholders would request dividends based on the amount of profit generated. This action reduced corporate assets. When the corporation borrowed money from creditors, its debt increased and the corporation assets increased. Since creditors do not have ownership of the company, the funds they provided the corporation were called external investment. The corporation had the obligation to pay interest and pay off the debt at the time of expiration, decreasing assets in the process. Most corporations placed the greatest value on net income, expressed by the increase in assets, when determining their ability to make money. Net loss after tax caused a decrease in assets.

This study used the annual reports of AUO from 2000 to 2010 converted into industry data. Government tax credit policies include the “High-tech Type 3 Stock Market Listing Law” of 1991, the “Statute for Upgrading Industries” of 1991, and the “Statute for Industry Innovation” of 2010. These policies were beneficial to industry financing and tax exemption. Note also that Taiwanese profit-seeking enterprise income tax rate was 25% until 2009. The equation descriptions of related variables for total assets are as follows. Figure 5 is a dynamic diagram of total assets.

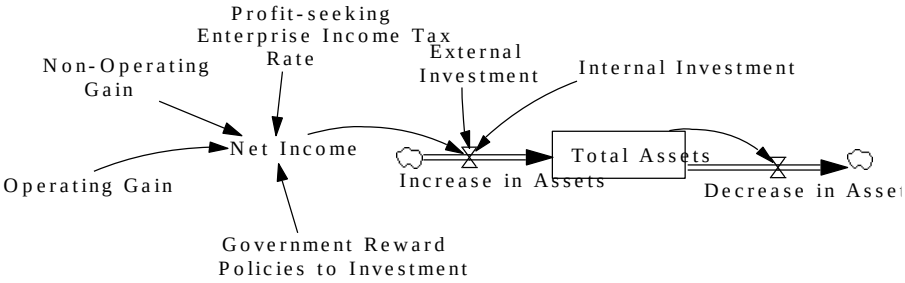

Fig. 5: Dynamic Diagram of Total Assets

4.4.3 Technology Levels

Since Taiwan was a latecomer to the large-sized TFT-LCD industry, it has struggled to catch up to South Korea and Japan. The highest generation factory currently in Taiwan is Generation 8.5 but Japan and South Korea is Generation 11, factories will began manufacturing in 2011. While Taiwan is behind Japan and Korea by 2.5 generations, through interviews with industry experts, it was determined that Taiwan was only trailing by one level of technology. This is because after new generation mass production, companies are able to quickly learn about next generation technologies either from other companies or from information provided at technology seminars. In terms of government support, due to the "Semiconductor Submicron Plan", the Ministry of Economic Affairs initially chose to establish the Vanguard International Semiconductor Corporation and ignored LCD display plans. Eventually, with the "Flat Panel Display Technology Development 4-Year Plan" that ran from 1993 to 1997, the government invested USD65.00 million and in the "Flat Panel Display Key Technology Development 6-year Plan" and a further USD123 million was invested in the industry. The government investment on R&D policy led to a time delay in the improvement of industry technology levels.

The 1997 Asian financial crisis forced Japan to transfer its large-sized TFT-LCD technology to Taiwan to obtain a large amount of royalties. This allowed Taiwan to develop its large-sized TFT-LCD industry. After 2003, Taiwanese corporations were able to develop and research their own industrial technologies and acted as partners with Japanese corporations instead of competitors. The equation descriptions of related variables for technology levels are as follows. Figure 6 is a dynamic diagram of technology levels. Figure 7 is a quantitative model for the Taiwanese large-sized TFT-LCD industry development.

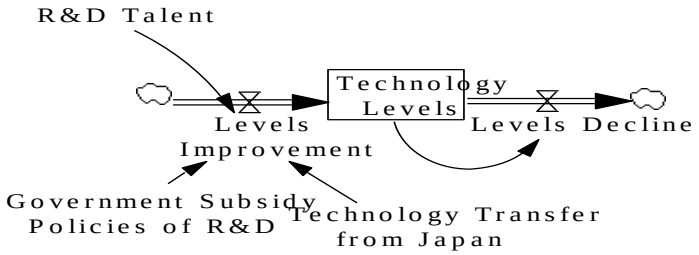

Fig. 6: Dynamic Diagram of Technology Levels

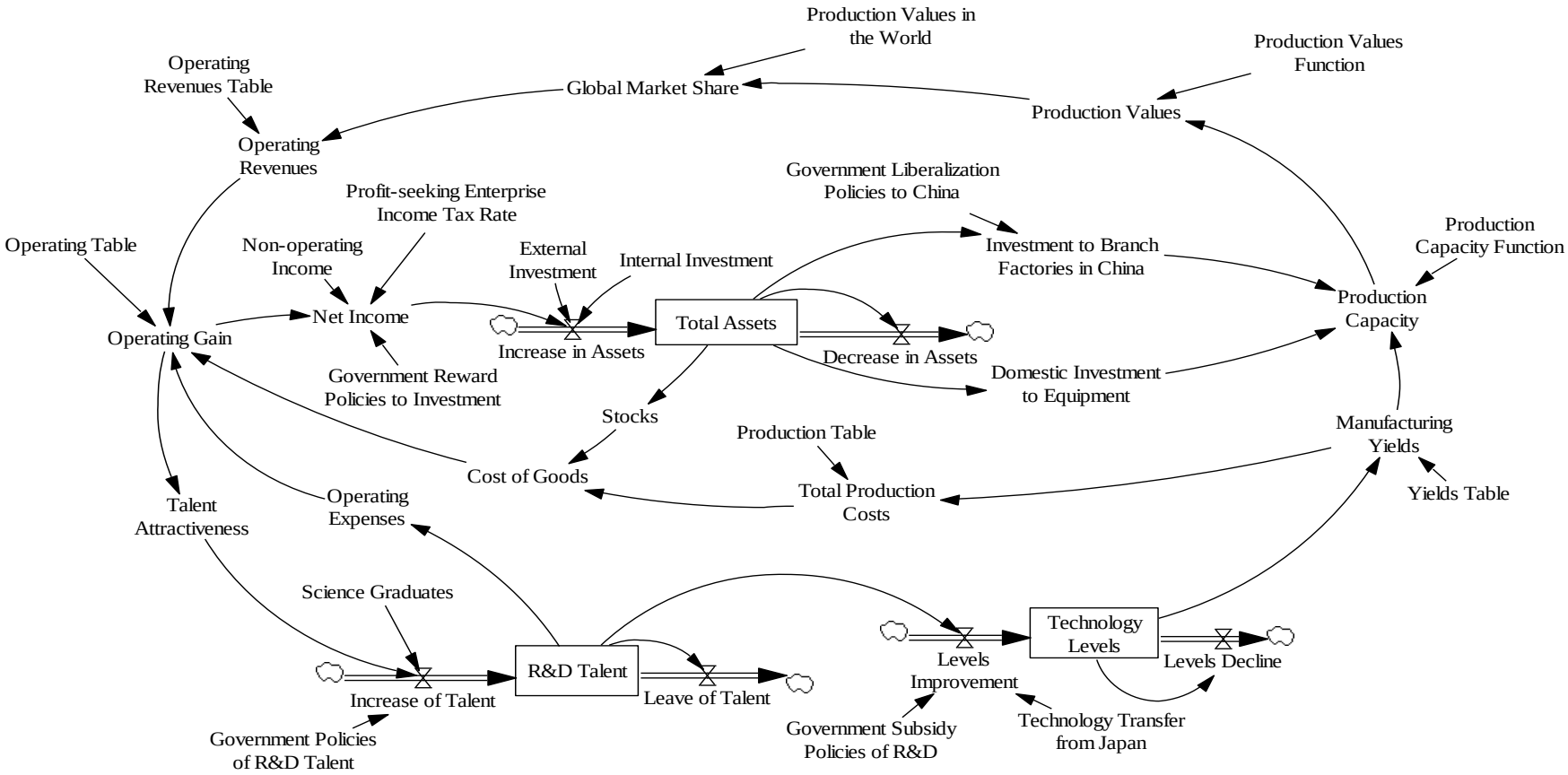

Fig. 7: A quantitative model for the Taiwanese large-sized TFT-LCD industry development

5. Results and Scenario Simulation

5.1 Results

Forrester & Senge (1980) described confidence in system dynamics models increased by a wide variety of tests that included tests of model structure, model behavior, and its policy implications. In terms of the structure of the model, this study mainly reviewed past literature and industry data, combined with a mental model for use in interviews with industry experts of Industrial Economics and Knowledge Center (IEK), and six top managers[2], to establish the causal relationships between the variables in the model. The variables in the quantitative model were derived from AUO annual reports, the Flat Panel Display Industry Yearbook, ITRI IEK, the Taiwan Industry Economics Services and Ministry of Education database, interviews with industry experts of IEK, and six top managers to compare and contrast the behaviors presented in the model and in real-world situations.

To observe the behavior of the development model, we focused on one level variable of the development model, technology levels. We simulated the period from 1997 to 2009, and then compared the results with the real historic data. In 1997, ADI (Japan) transferred Generation 2.5 of its mass production technology to Chunghwa Picture Tubes (Taiwan). This marked the official entry of Taiwan into the ranks of large-sized TFT-LCD mass production. The latest generation currently produced in Taiwan is at Generation 8.5 and Japan and South Korea are producing Generation 11 as of 2011. Figure 8 shows the trend of current values conforms to historical values.

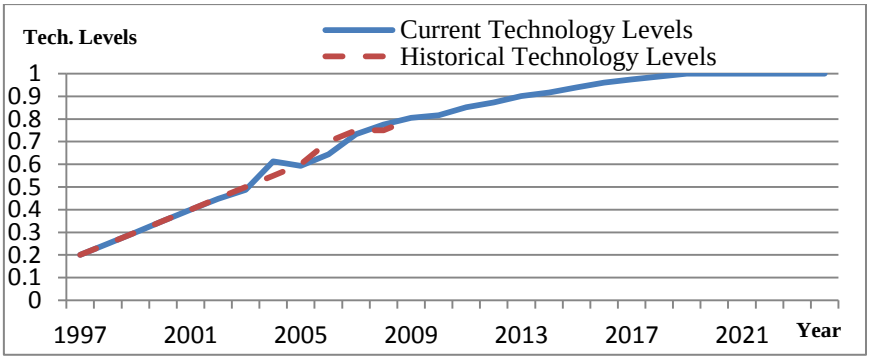

Fig. 8: A comparison for current and historical values of technology levels

5.2 Scenario Simulation

Taiwan's large-sized TFT-LCD industry has undergone four stages including TN-LCD stage, STN-LCD stage, small sized TFT-LCD stage, and large-sized TFT-LCD stage in accumulation of technology. The production values of Taiwan's large-sized

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[2] We are appreciated for the invaluable data and helpful comments from Mr. Yeh and Mr. Chen of IEK, Mr. Frank Wu as a vice president of AU Optronics, Prof. Hero Chiu as a senior director of Acer Group, Mr. Huang who is a manager in the dept. of technology transfer and development at UMC, and Mr. Hsieh who is a vice manager in the dept. of listing supervision at TWSE.

TFT-LCD industry were ranked second in the world from 2003 to 2009. During 2006 and 2007, these production values were even number one in the world for a short period of time. This section focuses on a simulation analysis and discussion of different policies.

5.2.1 Government Policy

Taiwan's flat panel display industry is a high-tech industry which the government has always put great emphasis on. The Taiwanese government had provided many positive policies to incentivize participation in the liquid crystal industry. This study will discuss and simulate scenarios to government policy, for example, profit-seeking enterprise income tax and government liberalization policies to China as follows.

The profit-seeking enterprise income tax rate is 25% and is used to calculate basic tax according to the Income Basic Tax Act. According to amendments to the Income Tax Act published in May, 2009, the profit-seeking enterprise income tax rate for enterprises was changed to 20%. However, the Taiwan government passed an amendment after a third reading that the profit-seeking enterprise income tax rate will be lowered from 20% to 17% from 2010. Therefore, the profit-seeking enterprise income tax rate for enterprises is 17% from 2010. Thus, the profit-seeking enterprise income tax rate of Taiwan is now lower than that of China (25%) and South Korea (22%), and comparable to that of Singapore (17%) and Hong Kong (16.5%). Net income is used to reveal the real earnings and predict future trends of industry development.

Figure 9 displays the simulated trend for the lowering of the profit-seeking enterprise income tax rate from 25% to 17% and to 16.5%. The lowering of the profit-seeking enterprise income tax rate to 17% has contributed to net income increases of the industry. However, the net income of the industry showed little difference whether the profit-seeking enterprise income tax rate was 17% or 16.5%.

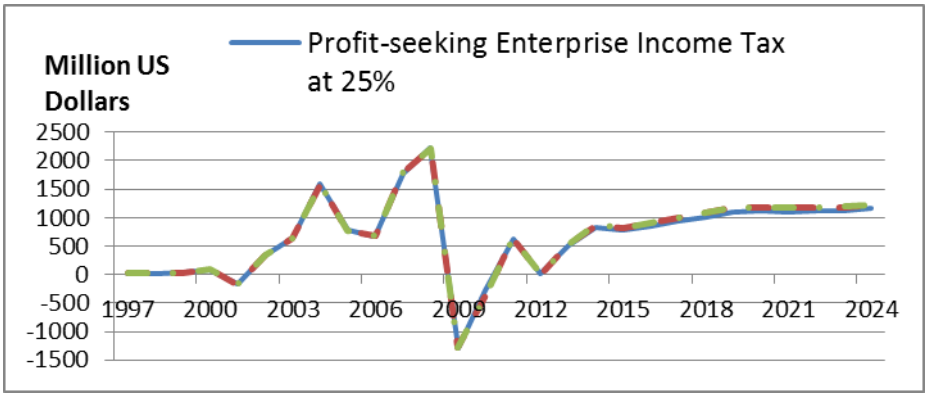

Fig. 9: Influence of Profit-seeking Enterprise Income Tax on Net Income

China is the fastest-growing terminal consumption market in the world. At the end of 2009, the Taiwan government issued approval for the flat panel industry to build plants under G6 without any restrictions in China. For generation plants above G6, the Taiwanese flat panel industry is only allowed to build plants with a lower technology level of at least one generation compared to plants in Taiwan. The industry should invest and conduct research and development in Taiwan. The number of plants to be built in

China should be limited to three and should be reviewed by the Key Technology Group. For AU Optronics, the restrictions on G7.5 investment in China were lifted at the end of 2010. Chimei Innolux Corporation indicates that they will apply for a lifting of this restriction soon. Figure 10 thus shows significant increases in production capacity.

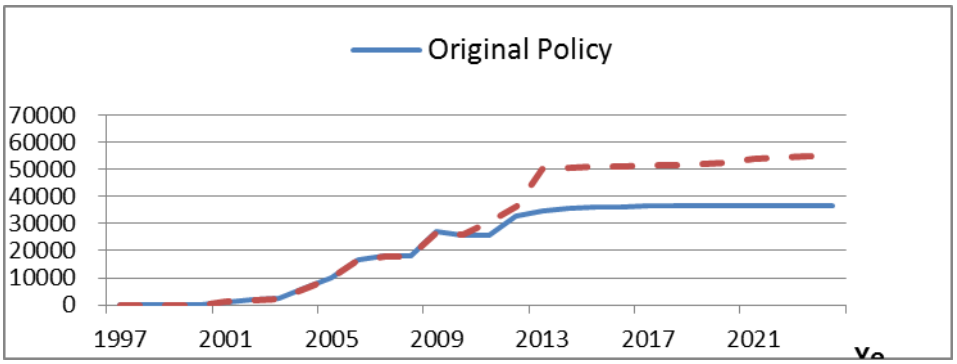

Fig. 10: Influence of Open Policy to China on Production Capacity

5.2.2 R&D Talents vs. Technology Levels

The development of technology levels of large-sized TFT-LCD lies not only in the equipment but also in the R&D talents. The current turnover rate for large-sized TFT-LCD R&D talents is about 10%. This study focused on the loss of human resources and simulated a situation in which the turnover rate increased from 10% to 20%. Figure 11 demonstrates a rapid decrease in technology levels due to high overall turnover rate, which lowers industry competitiveness.

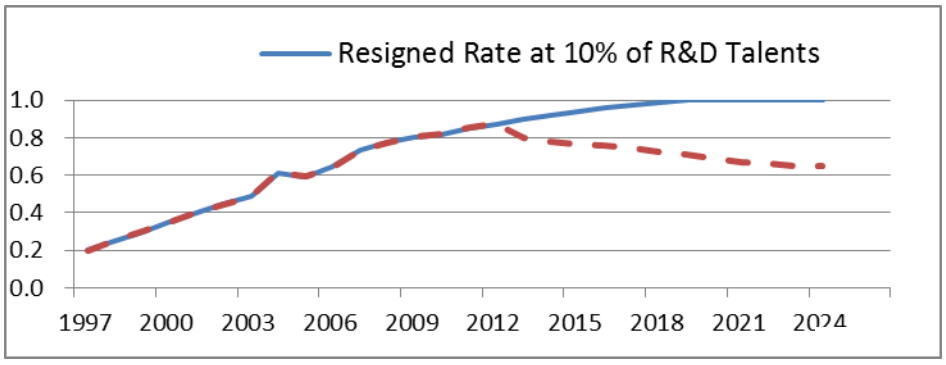

Fig. 11: Influence of Resigned Rate of R&D Talents on Technology Levels

6. Discussion

A seventh-generation fabrication factory required about 3,000 employees, TFT fabrication talents from the semiconductor industry and module assembly process talents was supported by the personal computer assembly industry. The challenge of talent bottlenecks meant that the government should be more active with TFT-LCD manufacturers to develop talent to avoid competition for talent between manufacturers within the industry; inter-manufacturer, and inter-industry overall cooperation is particularly important.

In addition, according to statistics from the Ministry of the Interior in Taiwan, the birth rate has been decreasing every year since 1963. The number of births decreased by

80,000 (20%) during 1980 to 1990 and 30,000 (10%) during 1990 to 2000. The number of births in 2010 was 16,600, which was 46.67 % less compared to 2000. Figure 13 shows the birth rate is decreasing rapidly. According to this trend, the birth rate in 2017 will show negative growth. The competitiveness of the TFT-LCD industry and other high-tech industries such as the information and communication industries will be greatly challenged and their future needs for high-tech talent will be affected.

To accumulate capital and technology levels, mergers and acquisitions of Taiwanese TFT-LCD manufacturers in recent years, such as the formation of AU Optronics from the merger of Unipac Optoelectronics Corp. and Acer Display Technology, Chi Mei's acquisition of IBM Japan, AU Optronics's 2006 acquisition of Quanta Display Inc., InnoLux merges with Toppoly and ChiMei in 2009, and Hon Hai Precision Industry Company Ltd. will be the largest stockholder of Sharp in 2012, this consolidation in capacity and in business models. Taiwan has been able to maintain its lead in the market; increasing economies of scale through mergers and acquisitions is highly important for manufacturers. Chang (2005) discussed the benefits obtained from mergers that result in more complete product lines and integrated resources to enhance competitiveness. It is predicted that the TFT-LCD industry will eventually be defined by a few manufacturers dominating the market.

Since Taiwan was a latecomer to the large-sized TFT-LCD industry, it has struggled to catch up with South Korea and Japan. South Korea and Japanese companies entered this industry first and applied for a considerable number of patents for inventions and prototypes. Therefore, how to overcome the problem of patent rights is a crucial issue. On the other hand, Taiwanese TFT-LCD companies produce TFT-LCD products from primary materials, which are limited to the primary source country of Japan. South Korea equipment may become the market mainstream in the near future. Development of the Taiwan flat panel display industry may face problems of obtaining primary material and equipment. The two issues mentioned above will be important research topics for Taiwanese industries to further improve their technology levels.

7. Conclusion

The high-tech industry is a capital- and technology-intensive, high-risk, and high return industry emphasized and nurtured by many newly industrialized countries (NICs). Thus, the creation of successful development experiences and models has become an important issue of discussion. After 30 years of development Taiwan's large-sized TFT-LCD industry holds the leading position in the global market. The development of Taiwanese large-sized TFT-LCD industry mainly affected by capital、R&D talent and technology level which three variables interact with each other. With the 1997 financial crisis, technology and key components were controlled by Japan and government policies to external environment, making the dynamic development structure of Taiwanese large-sized TFT-LCD industry which has particularity and complexity. It can be seen, NICs' large-sized TFT-LCD industry development has its own different circumstances, conditions and policies which lead to different system architecture. Therefore, NICs' large-sized TFT-LCD industry development has its commonality and particularity; we must study in depth on the national development model to be more circumspect understanding.

As example of Taiwan, because it is the industrial latecomer, it is difficult to break through patent protection and key components controlled by Japan, but also because of Taiwan's IC and NB Industries long-term accumulation of talents and technical supports, government incentives and the formation of the external environment successes to develop Taiwanese large-sized TFT-LCD industry, and ranked the number one, number two of the industry in the world. Therefore, the success of an industry with its external environment sporadically, but also need long-term consciousness to accumulate ability and capacities of related industries which is the necessary condition of developing successful an industry.

Successfully accumulating R&D talent, capital, and technology levels are essential to the development of large-sized TFT-LCD industry. This study used systems dynamics to show how the Taiwanese large-sized TFT-LCD industry became the first in the world within a short period of 30 years. The result shows that in addition to the three largest internal factors of accumulated R&D talent, capital, and technology levels needed for the industry. However, external factors of industry attractiveness, large-sized TFT-LCD technology transfer of Japan, and government policies also played significant roles that cannot be ignored in the vigorous development of this industry within a short period. Finally, this study makes some suggestions to industry participants, government, and researchers as follows.

7.1 Industry Participants

The Internet bubble of 2000 and the financial crisis of 2008 caused the loss of net income for these industries. The ability to respond to rapid changes in international economic cycles has become a key factor for long-term survival of the industry. At present, the population in China is more than 1.3 billion and accounts for 1/5 of the world's population. The mainland Chinese market will play a crucial role for global market demand of TFT-LCD products in the future.

7.2 Government

Taiwan is an export-oriented country; the financial tsunami of 2008 has led to a weakening of global market demand. The government should force manufacturers to focus on leadership to form greater influence in the market. It should be serious and thought-provoking questions faced by the Taiwanese government. In addition, the government should actively formulate effective policies to help the industry regarding future challenges from the dynamic environment.

7.3 Researchers

The success of Taiwanese large-sized TFT-LCD industry is a valuable example to NICs and developing countries that need to develop high-tech industry. Lastly, although the successful development and model of high-tech industries still offers a path for NICs to reference, the system structure and environment for every industry is different and requires continual interaction adjustments between system components and environmental variables to achieve the self-development of successful industry system structures. System dynamics is also suitable for tracing the development of Taiwanese large-sized TFT-LCD industry, Integrated Circuit (IC) industry, and Personal Computer (PC) industry after Economic Cooperation Framework Agreement (ECFA) and further, even the development of the photovoltaic industry in the future.

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產業發展之資源累積模式–以台灣為例

黃慧華[3]

摘要

顯示器產業是繼半導體產業之後，全球重要的高科技產業之一，整體顯示器產業中，無論以產值或產能而言，都以薄膜電晶體液晶顯示器(Thin Film Transistor Liquid Crystal Display；TFT-LCD)產業占最大部份。以 2015 年為例，台灣大型 TFT-LCD 的產值為 19,423.21 百萬美元，居全球第二。事實上，台灣大型 TFT-LCD 產業發展是一個動態資源累積的過程，由許多因素之間彼此牽動並且相互影響，形成一個複雜的產業發展系統。本研究應用系統動態學建構台灣大型 TFT-LCD 產業發展的結構，以了解其產業發展的系統行為。研究顯示：研發人力、資產、技術水準為台灣大型 TFT-LCD 產業成功發展的最主要的三個積量，同時，還需要外在環境變數的支援，包括：產業吸引力，來自日本大型 TFT-LCD 技術的移轉和政府政策等因素的影響。最後，本研究針對台灣大型 TFT-LCD 產業發展做相關趨勢的模擬與建議。

關鍵詞：顯示器產業；半導體產業；高科技產業；薄膜電晶體液晶顯示器(TFT-LCD)；系統動態學

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