An Exploration of Patent Analysis and R&D of the Organic Silicon Industry

Shang-Yung Yen*

Feng-Chia University

Yu-Chieh Liang

Feng-Chia University

Abstract

This study aims to explore the correlation between new product development (NPD) and the technology patent portfolio with the silicon industry as a case study. During the exploration, the major indicators for the correlation are the ones related to the NPD and the technology patent portfolio in small and medium enterprises (SMEs). When the technology layout of the organic silicon industry is being studied, this research tries to establish a mode for the NPD and technology patent portfolio based on a theoretical and practical foundation. In this way, it is hoped that the gap can be filled in both theory and practice. After the research, the following findings are revealed.

(1) Taiwan government provide scarce support to SMEs that facilitates the development of the organic silicon industry. (2) The development of the organic silicon industry in Taiwan is limited by the small size of the organic silicon enterprises. The incomplete financial and capital structure, the insufficient human resources, and limited technical resources prevent the SMEs from investing in research and development (R&D).

Keywords: Organic Silicon, Patent, R&D

* Contact email: stephenyen0225@gmail.com.

I. Introduction

The worldwide rapid advances of the electronic information technology promote the development of the organic silicon industry. The silicon materials are widely applied to all industrial and high-tech fields, such as construction projects, textiles, electronics, transportation, petrochemical industry, aerospace industry, new energies, medical treatment, mechanical engineering, and personal care. Now the silicon industry is growing much closer to people's daily life, industrial and agricultural production, and high-tech development. It is an indispensable high-performance material for the modern industry and our daily life. Nowadays, the silicon industry has become one of the largest among the industries of new polymer materials[1].

1.1 Applications of silicon

At present, silicon materials have been widely used in all walks of life, some of which are mature, and some of which are still researched and developed to expand their scope of application. It is most widely used in the industrial field. Moreover, their application in agriculture, tertiary industry and information industry has also developed rapidly in recent years. The industrial application of silicon began in the military industry. After the World War II, its application scope gradually expanded with the development of material properties. Silicon is widely used as a desiccant. With the accelerating process of labor specialization, it is utilized in the petrochemical, pharmaceutical, food, biochemistry, environmental protection, coatings, light textile, paper, ink, plastic and other industrial fields. The quality and technical standards of silicon is advancing rapidly in the recent decade. The silicon used in food, medicine, and biochemistry is mainly nano silicon. The relevant technology is maturing and has a considerable production scale abroad. The production method used for this type of product is to wash and dry silicon before carrying out nano treatments to make it amorphous.

Silicon is a new high-tech material. The high-performance downstream silicon products play an indispensable role as basic materials in emerging industries, such as new energy, information technology, aerospace, healthcare and high-end manufacturing. If material development does not keep up with the industrial demand, it will seriously impede the development of relevant emerging silicon industries. For the organic industry, which has distinct characteristics of emerging industries, it is necessary to adjust industrial structure, improve technologies, and give impetus to the industry to achieve a high-end development through research into new products and technological innovation.

[1] Hsin-Ping Pu (2011), *Status and Forecasting of Silicone Industry in China*. Silicone Material, Vol.25 (5), pp. 333-342.

Table 1: Silicones – *How and Why They are Used*

Market	Important uses
Transportation	Silicones are used in various components within automobiles in the car manufacturing industry. Silicones are also used extensively in the marine vessels manufacturing. Due to their unique properties, they are also used extensively and increasingly in aviation and avionics components.
Construction materials	Silicones are used to seal joints and openings in various applications in commercial construction. They are also extensively used in domestic do-it-yourself (DIY) applications, and in sealants for joints in paving, decks and concrete slabs. They are also widely used in interiors in floor joints, bathtubs, sinks, and showers to prevent water leakage and subsequent damage.
Electronics	Silicone sealants, adhesives and coatings are used, among other things, to produce circuits, connectors, capacitors, coils, transistors and tubes in electronic devices for most consumer and business applications.
Energy	Silicones are also an important insulating component in energy transmission and distribution.
Health care	Silicones are one of the most widely applied biomaterials, and they have been used in a wide range of health care applicants, including orthopedics, catheters, drains and shunts, components in kidney dialysis, blood-oxygenator, heart-bypass machines, heart valves and aesthetic implants amongst others. Some of the main applications include: molds, tubing and various ‘enabling components’; adhesives and coatings; antifoams; control release devices; lubrication; and topical medication.
Industrial processes	Silicones are used to enhance coatings, providing various components with increased durability and resistance to chemicals, corrosion and high temperatures, reducing maintenance costs or unplanned maintenance for industrial infrastructure and machinery Silicones’ properties enable them to be used as hydraulic fluids and additives for polymers for a variety of applications.
Personal care and consumer products	Silicone polymers and cyclic siloxanes, (referred to here under the generic term ‘silicones’) are used in the personal care sector as a solvent and carrier for a number of personal care products, including deodorants, haircare products, sun-care products, skin-care products and make-up products. Silicones are also used in various components within other consumer products, including cooking utensils, sporting goods, baby and infant products, and furniture and bedding, among others.
Special systems	Silicones are used as a solvent and carrier in a number of ‘special system’ processes, including coatings (e.g. for textiles, leather, paper, packaging, labels, parachutes and air bags).

Source: Socio-economic evaluation of the global silicones industry (2016, 3)

Globally, the organic silicon industry is mainly dominated by Dow Corning (US), Momentive Performance Materials, Shin Etsu (Japan) and Wacker Chemie (Germany). These four enterprises accounted for 79 percent of the global organic silicon market in 2010[2]. China is the world's major producer of silicon, and its current production capacity is about 770,000 tons/year. Since 2010, its production of industrial silicon has reached more than 400,000 tons per year, accounting for about one third of the world's total output of industrial silicon. Taiwan is lacking in upstream raw materials for organic silicon production. The Taiwanese manufacturing enterprises of organic silicon for downstream applications are relatively small both in size and in quantity. Currently, among the four major organic silicon manufacturers, all manufacturers have established sales centers in Taiwan, except for Momentive Performance Materials. In particular, Shin Etsu has set up a production plant for organic silicon downstream products in Taiwan. In the upstream monomer production of organic silicon, most Taiwanese manufacturers rely on imports. Currently, some have already had the technology that organic silicon is used as the LED packaging material among the Taiwanese manufacturers that are developing organic silicon downstream products. There are also some manufacturers who have put silicon into production use in other areas, such as electronic products, construction, industrial additives, and other organic silicon related applications. Overall, there are only a few companies that have invested in the development of organic silicon products in Taiwan, and most of them are SMEs with a capital of less than NT$1 billion. Taiwan's application ability of organic silicon downstream products is far behind that of Mainland China.

As there are still many uses of organic silicon waiting to be developed, the organic silicon industry still has a high growth potential globally. However, the market is taken by a few industry players, of which Dow Corning has a global market share of nearly 40%, and its downstream products exceed 7,000 types. It is the world's leader of the organic silicon industry. Optoelectronics, automotive and other fields are the target markets of major manufacturers. Mainland China is an emerging market, of which major manufacturers aim to take a slice. In Mainland China, there are oversupplied upstream monomers in the organic silicon industry, but only a few monomer types. Its demand for downstream organic silicon products has grown rapidly, but there are only a few product types, and the manufacturing of special-purpose products still rely heavily on imports. In the ECFA early harvest list that has been signed, some organic silicon products have been included in the early harvest projects across Taiwan Strait. Taiwanese companies introduce low-priced products from Mainland China because of the benefits that the ECFA early harvest list brought them. It will be a new opportunity for Taiwan to develop the organic silicon industry by combining it with other industries such as medical, healthcare, petrochemical,

[2] Yu-Cheng Chen (2011), *Present Situation of Silicone-related Industry in the World and Mainland China*. Industrial Materials, pp.126-133.

electronics, semiconductors, and automobiles, and adding processing value so as to develop new applications in the downstream organic silicon industry. This is also the motivation of this study.

1.2 Research Purposes

Enterprises attach great importance to the investment in R&D and innovation. On the other hand, how companies appropriately promote the NPD and technology patent portfolio is difficult and complex, especially in the face of limited resources and uncertainties in the industrial developmental environment. Industrial upgrading is an issue that a nation and its enterprises face at all times. Therefore, enterprises must grasp the global economic pulsation and industrial development trends in order to formulate the future direction of new product development. In this aspect, the technology patent portfolio is a strategy that helps protect new product development know-how. In this study, whether the technology patent portfolio can give enterprises an impetus, bringing opportunities to their future new product innovation and development in terms of R&D, patents, technology, and innovation.

This study examines the correlation between the NPD in Taiwanese enterprises and technology patent portfolio with a case study of the silicon Industry. Most previous researches focus on multinational corporations that plan their technology patent portfolio through mergers and acquisitions to ensure the proprietary and Inviolability of their corporate products. There are inadequate studies on the NPD and technology patent portfolio for SMEs. Whether the influence of technology patent portfolio on new product development can bring new opportunities for enterprises is the main purpose of this research. It is hoped that the research has both theoretical and practical contributions.

II. Overview of the Organic Silicon Industry Market

2.1 Overview of the Global Silicon Industry Market

Silicon rubber was developed in the 1940s. The earliest research of it was dimethyl silicon rubber. In 1943, Dow Corning and General Electric started producing it, respectively. Room temperature vulcanization (RTV) silicone was first introduced in 1954. In Mainland China, it was put into industrial production in the early 1960s. The main countries producing it today include China, the United States, UK, Japan, and Germany. Branson[3] believes that the process of developing a specific technology or method to solve a problem can be called R&D. Lau[4] defines R&D as organizational investment and research activities for continuously

---

[3] Branson, J. (1966), *Transfer Technology Knowledge by International Corporation to Developing Countries*, American Economics Review, May, pp.259-267.

[4] Lau, R. S. M. (1998), How Does *Research and Development Intensity Affect Business Performance?*, South Dakota Business Review, Vol.57(1), pp.4-8.

improving products and processes. It is an important event for high-tech companies. In the past 30 years, products have been continuously innovated and technologies have been continuously upgraded. The large scale production of silicon globally has become the mainstream for major multinational companies. Adam Jeffe (1985; 1986; 1988) found in most of his relevant studies that "growth of corporate productivity" is positively correlated with another two variables, i.e. "Average R&D Investment" and "Scale Change of R&D Accumulation." Bommer and Jalajas[5] studied the difference in the source of innovation between large enterprises and SMEs. Large enterprises placed greater emphasis on process innovation. Therefore, the source of innovation is mainly upstream suppliers.

2.2. Overview of North American Silicon Market

The United States is a key silicon market in the North American region. In 2011, the US silicon market became saturated. Accordingly, the outlook of the silicon industry was not as good as expected. On the other hand, its downstream silicon industries are still growing at a rate of 4% per year. Over the years, with leading innovative ideas and strong R&D capabilities, the brand effect of North American silica gel gradually takes shape, and it improved its status of silicon products across the globe[6].

2.3. Overview of Taiwan's Organic Silicon Market

At present, Taiwan's organic silicon industry is incomplete. It lacks an upstream organic silicon raw material supply chain. Domestically, it only has midstream processing and downstream applications. Most Taiwan's manufacturers use imported raw rubber as raw materials. After that, they export silicon products after plastic processing, or manufacture downstream application products and make sales. The import and export data in Figure 1 show that in recent years Taiwan has increased in silicon rubber imports and declined exports. As a result, net imports have gradually increased. In 2015, net imports of Taiwan's rubber have reached 3,255 metric tons, which is over three times than 2011. In addition to the increase in the domestic industry demand, the rise in OEM products (the processed products will be exported under the names of other goods) is also one of the growth factors.

[5] Bommer, M. and Jalajas, D. S.(2004), I*nnovation Sources of Large and Small Technology-Based Firms*, IEEE Transaction Engineering Management, Vol.51(1), pp.13-18.

[6] Bosi Data Research Center (2011), *Report on the Market Supply and Demand and Investment Prospects of China's Silicone Industry 2011-2015*.

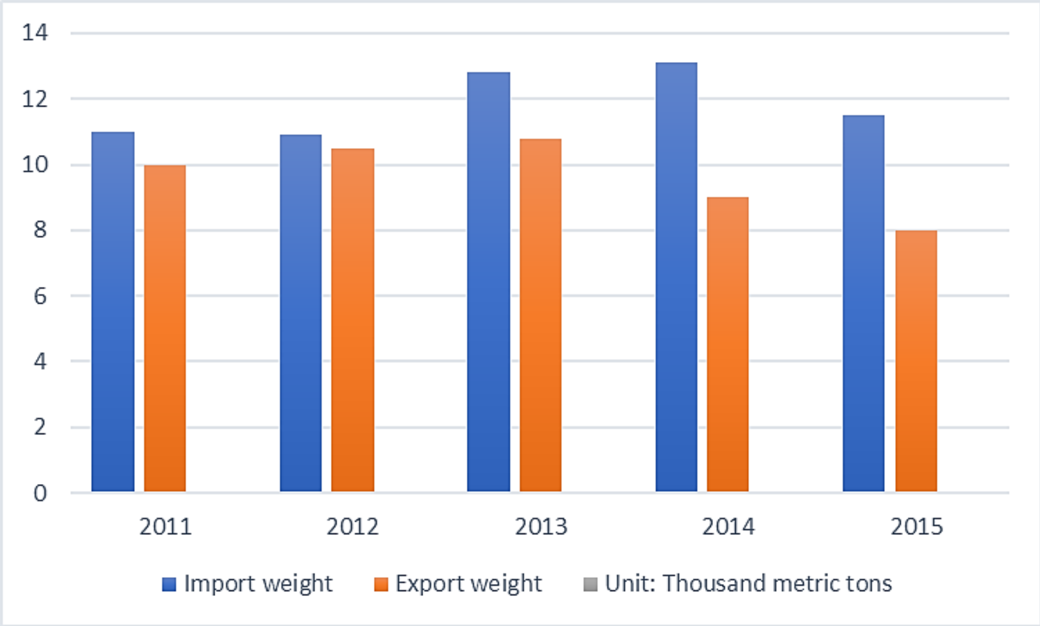
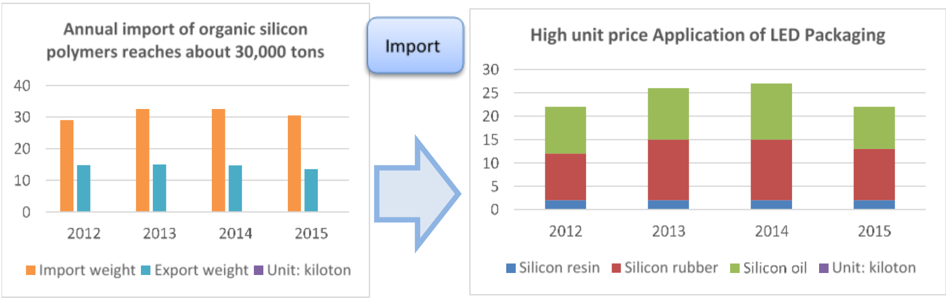


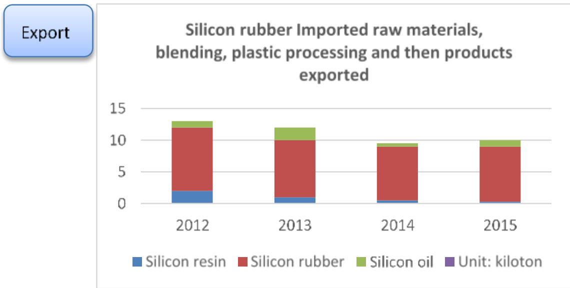
Figure 1: Import and Export Data for Taiwan Rubber

Source: ITIS Taiwan Import and Export Data collated by IEK in August of 2016

The annual import volume of organic silicon in Taiwan is about 30 thousand metric tons, of which about 11 thousand metric tons is consumed by the domestic market. The domestic organic silicon downstream application market is dominated by construction, electronic glue, solar energy, LED, industrial components, industrial additives, textile additives, coatings, and medical materials. The organic silicon monomer is the gap of Taiwan's industrial chain, and there are also scarce downstream manufacturers with organic silicon polymerization technology. About 1,000 metric tons of medical materials made of organic silicon are consumed per year. They are mainly supplied to Taiwan's manufacturers by Wacker, Dow Corning, and Shin-Etsu.

According to the data collated by the Industrial Technology Research Institute in 2016, Taiwan imports30,000 metric tons of organic silicon polymers annually. The analysis for its imports and exports is shown in Figure 2.





3910 Polysiloxane	
CCC code	Chinese
39100010001	Silicon oil
39100020009	a cream containing silicon oil
39100030007	Silicon resin
39100040005	Silicon rubber
39100090004	Other types of polysiloxane, primary state

Figure 2 : Analysis for Taiwan's Organic Silicon Import and Export

Source: ITIS Taiwan Import and Export Data collated by IEK in May of 2016

According to a further analysis by the Taiwan-based silicon-related companies, the gap in Taiwan's industrial chain lies in organic silicon monomers. Methyl chlorosilane is only an intermediate or by-product for solar silicon manufacturers, such as Baolian Energy and Baode Energy. There are no specialized manufacturers of organic silicon monomers. Among the manufacturers with organic silicon polymerization technology, only Eternal Materials produce commercial products in a relatively large scale. Taiwan's companies that are involved in the organic silicon industrial chain, from the raw materials, monomers, and polymers to the downstream applications, are shown in Figure 3.

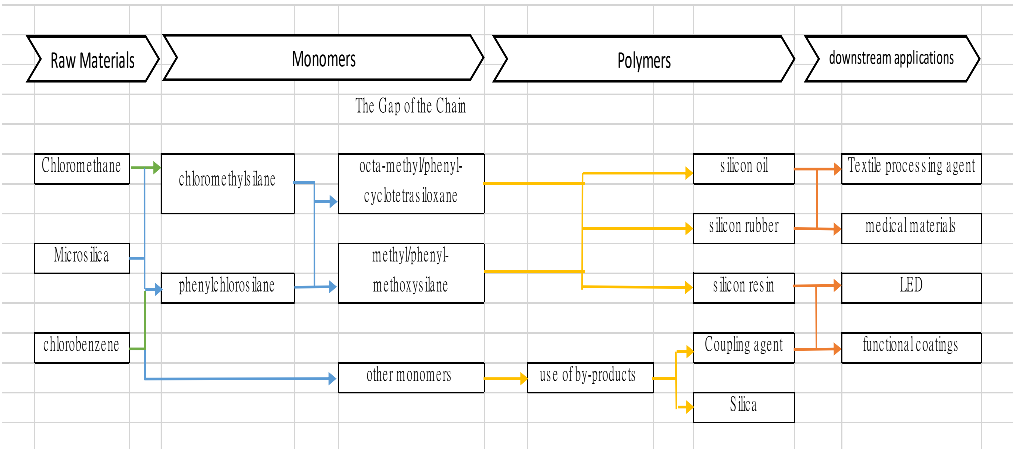


Figure 3: Taiwan's Organic Silicon Industrial Chain

Source: ITIS Taiwan Import and Export Data collated by IEK in August of 2016

III. Patent portfolio

The patent portfolio is a purposeful and strategic patent portfolio process, and the action is taken to achieve a given goal. The patent portfolio often requires strategic thinking to make plans. Therefore, the patent portfolio is often discussed with the patent strategy. Berkowitz[7] interprets the patent portfolio as a tool that allows enterprises to ensure their competitive advantages. Knight (2001) considers the patent portfolio as a scientific art that combines business, law, and technology ingeniously. Somaya (2002) believes that the patent strategy is a tool of pursuing competitive advantages by acquiring patents and managing them properly.

The use of patents, technologies, and business strategies is all related to corporate values. The existence of business lies in its capacity of making money and of developing sustainably. The business layout, patent portfolio and technology layout are all similar in this aspect. Moreover, the patent portfolio includes applying for patents in person or obtaining others' patents, such as the purchase of an independent inventor's patent and the acquisition of core technologies from institutions of higher learning. You can develop your own technology and apply for a patent afterwards. You can also entrust other parties to carry out technological development and apply for patents in person. Or, you can develop with others jointly and apply for a patent on your own or jointly.

The patents used in the commercial field are often regarded as a means to achieve commercial purposes, which can be understood as a patent application. In general, this includes applying the patent to products that one wants to sell (most in this category). Other uses include new start-ups, price-based investment, patent authorization, technology transfer, sale and purchase, infringement litigation, technical standards, and patent alliances.

After understanding the aforesaid integration of patents, technologies and business layouts and strategies, two key intelligence needs should be met before enterprises formulate their own patent portfolio strategies. This includes investigating the various links of the aforesaid patent, technology, and commercial layout (basically macro information) in specific industrial ecosystems, including the authorities, enterprises, research institutions, schools, and individuals.

According to the above-mentioned scholars, Taiwanese enterprises oriented to knowledge and technology exports will exert a decisive influence on the industrial development and business operations by implementing the plan for the technology patent portfolio in the face of a competitive environment that shifts from a regional trend to a global one.

---

[7] Berkowitz L. (1993), *Aggression: Its Causes, Consequences and Control*, New York: Mcgraw-Hill.

3.1 Patent Analysis

Patent analysis refers to the statistics, analysis, and comparison of the information contained in patent documents. It is widely used in the study of R&D energy of a nation, technological field, industrial departments, and corporations[8]. Its significance lies in transforming patent data into more valuable information, changing the scattered patent data into systematic and valuable patent knowledge, and further serving as a basis for judging industrial competition, analysis of technology trends, and scope of power. The relevant application scope can be used to analyze the R&D trends of competitors' products, important inventors, and technology R&D layouts. Moreover, related information can be utilized to analyze technology R&D planning, technology introduction, patent portfolio, and patent applications. It can even be used for the reference of the market layout. Yoon and Kim[9] developed an intelligent system for locating emerging technology trends based on patent data. Tsuji[10] understands the evolution of the technology development process based on the patent information.

Mainly, there are three sources of information that predicts effectively current technological changes, namely published journals and documents, technical-related seminar conference papers, and patent information. According to the report of the World Intellectual Property Organization (WIPO), among the information related to technical development in various professional journals, magazines, and encyclopedias, only the patent information can fully disclose the core technology. The patent specifications reveal 90% to 95% of R&D achievements. However, 80% of them are not recorded in magazines and journals. According to a survey conducted by the WIPO, the effective use of patent information can reduce time for research and development by 60% and save research funding by 40%[11]. Ashton and Sen[12] proposed the five main applications of patent information for business operation planning: technology competition analysis, new business evaluation, patent portfolio management, R&D management, and monitoring of product ranges. Mogee[13] believes that patent analysis is of the following four application values, namely rival

---

8 Pavitt K. (1988), *Uses and Abuses of Patent Statistics, in Handbook of Quantitative Studies of Science and Technology* (edited by Raan V.), Amsterdam:Elsevier Science Publishers.

9 Yoon, J., Kim, K., 2012a. An analysis of property–function based patent networks for strategic R&D planning in fast-moving industries: the case of siliconbased thin film solar cells. Expert Syst. Appl, Vol. 39 (9), pp.7709–7717.

10 Tsuji, Y.S. (2012), *Profiling technology development process using patent data analysis: a case study*, Technology Analysis & Strategic Management, Vol.24(3), pp.299-310. doi: 10.1080/0953 7325.2012.655417.

11 Hsiao-Lin Wu (1998), *Patent Management Facilitates Technological Development*. *Master of Patent Management*, Taipei: Science and Technology Law Institute, pp.3-7.

12 Ashton, W. B., and Sen, R. K. (1988), *Using patent information in technology business planning I.*, Research Technology Management, Vol.31(6), pp.42-46.

13 Mogee, M. E. (1991), *Using patent data for technology analysis and planning*, Research-Technology Management, July-August, pp.43–49.

analysis, technology tracking forecasting, identifying important developments, and international strategic analysis. Yu-Chi Shao[14] proposed the application of patent map analysis at various stages of scientific and technological research and development projects. It is mainly used to understand what kind of technology a competitive company takes lead in, the evolution of technological trends, and the formulation of the strategies against patent infringement, clarification of the direction of technology research and development, and the setting of technological sources.

Patent analysis can be applied to understand trends in national competition[15], industrial competitiveness[16], corporate competitiveness (Ernst, 1995) and emerging technologies[17]. According to the purpose of the analysis, the items to be understood can be chosen for statistical calculations or graphic presentations in different ways so as to facilitate subsequent interpretation of patent information. This is a necessary method and process for understanding and using the value of patents. For some SMEs, making good use of patent information will provide a blueprint for the future development of the company's strategy[18].

IV. Factors Affecting R&D Investment

4.1 External Factors Affecting R&D Investment

4.1.1 Industrial Type and Market Concentration

The type of the industry and the degree of market concentration are considered as external factors that affect a company's R&D investment. Schumpeter[19], an economist who first proposed the impact of "innovation" on economic structural changes, believes that industry characteristics are relative factors that influence a company's investment in R&D. Lee[20] studied the stimulating effect of competitive market pressure on a company's investment in R&D. It was found that the response of a company's R&D activities to the competitive market pressure mainly depends

---

14 Yu-Chi Shao (1995), *Tools for Industrial Upgrading—Patent Map*, CCL Technical Journal, Vol.37, pp. 60-68.

15 Furman, J. L., Porter, M. E., & Stern, S. (2002), *The determinants of national innovative capacity*, Research Policy, Vol.31(6), pp.899-933.

16 Cooper, R. S., and Merrill, S. A. (1997), *U.S. Industry: Restructuring and Renewal – Industrial Research and Innovation Indicators*, Washington, D.C.: National Academy Press.

17 Abraham, B. P., and Moitra, S. D. (2001), *Innovation Assessment through Patent Analysis*, Technovation, Vol.21(4), pp.45-252.

18 Grupp, G., and Schmoch, U. (1999), Patent statistics in the age of globalization: new economic interpretation, Research Policy, Vol.28(4), pp.377-396.

19 Schumpeter, J.A. (1942), *Capitalism, Socialism and Democracy*, New York: Harper and Brothers.

20 Lee, I.H. and Marvel M.R.(2009), *The moderating effects of home region orientation on R&D investment and international SME performance: Lessons from Korea*, European Management Journal, Vol.27(5), pp.316-326.

on the company's technical level or its R&D productivity. The data of the survey on companies by the World Bank show that the difference in the company's technical level leads to the difference in the impact of the competitive market pressure on the company's R&D activities. For the companies with flexibility, the company's technical capabilities have the most significant impact on its relationship between R&D and the competition.

4.1.2Supportsfrom Governmental Policies

The Chinese government is most active in terms of the policy on R&D. Guan et al.[21] studied 1,244 companies in Beijing, exploring the relative importance of identifying different innovation goals and manufacturing enterprises' innovation strategies. The research shows that most companies' innovation activities are limited to improving product quality. Through the certification of high-tech enterprises, the manufacturing enterprises that have received support from the Chinese government have begun to rid the dependence on the introduction of technology and equipment. Moreover, they can promote the market economy through R&D and innovation. Brian[22] validated the economic benefits of R&D projects under the sponsorship of the Canadian government. He used various methods and indicators to evaluate the advantages of R&D projects and the enterprises supported by the government, and to use existing information related to R&D projects to learn which indicators and methods can be used for practical operations.

4.2 Internal Factors Affecting R&D Investment

4.2.1 Enterprise Scale

The scale of an enterprise is a factor that affects R&D investment the most. Schumpeter[23] believes that only large enterprises can afford R&D costs. Large-scale enterprises with diversified businesses can reduce the risk of failure through a larger range of R&D innovations. Therefore, large enterprises can bear a larger proportion of innovation than small ones. Galende and Suarez (1999) believe that the relationship between the size of an enterprise and its willingness to engage in R&D activities is complex and difficult to generalize with a simple assumption. General research observations show that the larger an enterprise is, the more likely it is to engage in R&D. Coad and Rao[24] observes the correlation between internal sales, employee growth, profit growth, and R&D expenditure vertically. The empirical

---

[21] Guan J.C. ET AL. (2008), *Innovation strategy and performance during economic transition: Evidences in Beijing, China*, Research Policy, Vol.38(5), pp.802-812.

[22] Brian P. C. (2008), *Data and the measurement of R&D program impacts*, Evaluation and Program Planning, Vol.31(3), pp.284-298.

[23] Schumpeter, J.A. (1942), *Capitalism, Socialism and Democracy*, New York: Harper and Brothers.

[24] Coad A. and Rao R. (2010), *Firm growth and R&D expenditure, Economics of Innovation and New Technology*, Vol.19(2), pp.127-145.

results show that an enterprise's profit growth has little relevance to R&D investment. However, if the company grows in sales and the number of employees, its R&D expenditure will increase. That is to say, when the company grows in scale, it will engage in more R&D investment activities.

4.2.2 Financial and Capital Structure

Bushee[25] believes that the level of operating cash flow is related to whether the R&D expenditure is easy or hard to get. When an enterprise has abundant capital, it has higher chances of making investment. The reason why enterprises prefer internal funds to meet the funding needs for investment is that due to the imperfection of the capital market, external financing incurs much higher costs than internal capital because of the factors such as transaction costs, agency problems, and information asymmetry. Furthermore, an enterprise's investment plan may involve trade secrets, and senior management may be unwilling to disclose them. Therefore, most ordinary enterprises choose to supply the funds needed for the investment with internal resources. The operating cash is the one of enterprises' sources of their own funds. Galende and Suarez[26] believe that an enterprise's financial resources will affect its tendency to engage in R&D activities.

4.2.3 Human and Technical Resources

Teece[27] believes that because of the characteristics of R&D activities, such as a high investment, a high risk, and a long cycle, imitation costs are relatively high. Existing manufacturers in the market obtain patent protection and complementary assets by investing in R&D. The combination of R&D activities with these resources facilitates the formation of an organization's specific assets. In this way, its products can not be easily imitated by other competitors. Galende and Suarez[28] also believe that the company's personal experience, knowledge, judgment, skills, risk proneness, and wisdom are necessary resources for corporate innovation. In addition to the materials required by the research, it also includes whether there is a team of highly qualified scientists and engineers. This means that the integration of skills and knowledge into the organization will undoubtedly exert a positive effect on its R&D activities. Evangelista and Savona (2003) conducted an empirical study on the innovations of the enterprises involved in the Italian tertiary industry and found that the number of employees in a company has a positive correlation with R&D

---

25 Bushee, B.J. (1998), *The Influence of Institutional Investors on Myopic R&D Investment Behavior*, Accounting Review, Vol.73(3), pp.305-33.

26 Galende Del Canto, Jesús and Suárez-González, Isabel (1999), *A Resource-Based Analysis of the Factors Determining a Firm's R&D Activities*, Research Policy, Vol.28, pp.891-905, 10.1016/S0048-7333(99)00029-3.

27 Teece D.J. (1986), *Profiting from Technological Innovation: Implications for Integration, Collaboration, and Licensing, and Public Policy*, Research Policy, Vol.15(6), pp.285-305.

28 supra note 26.

expenditures. It also shows that when the company's production scale expands, it also has an increasing demand for human resources because it starts engaging in the R&D activities. In addition, technological innovation of enterprises is mainly measured by R&D expenditures and input by R&D personnel in the aspect of knowledge input.

V. Research Results

5.1. Research Methods

This research mainly uses the Technology-Function Matrix of the technology patent portfolio as a tool for analysis. The Technology-Function Matrix can group related patents to observe the focus in the matrix and patent blanks. After the technical efficiency matrix diagram is formed, the key areas of the technology, the so-called patented minefields, can be seen at a glance. The technology gap with a small number of technologies in the block can also be found. The avoidance design of the technical barriers for developers and the setting of key technologies can be identified. Both of them have important guiding significance in determining strategies[29]. Therefore, it can be seen whether the organic materials between different materials have sufficient ability to serve as a substitute and show their performance in various aspects.

5.2 Research Results for the Analysis of the Number of Patents

The analysis of the number of patents mainly analyzes the trend of the number of patent applications/approval announcements in the field of silicon technology. In this way, the changes in the number of silicone technology patents are observed, and in-depth discussions on the development trends of the number of patentees (competing companies) that invest in silicon technology are conducted as an important reference for technical development prediction.

This study analyzes the trend analysis of the number of patents, and changes in patent applications, patent announcements, number of patents, and number of patents that have been filed over the years.

---

[29] Shan-Yao Wu and Chih-Chieh Hsiao (2012), *Using Patent Analysis to Explore the Development Trend of Golf Club Industry in Taiwan*. Journal of Global Business Operation and Management, Vol. (4), pp.83-94.

Table 2: The Changing Trends in the Number of Global Patents:
Mainly from the Year Wherein the Patents Were Applied

Year	The number of applicants	The Number of patents
1983	1	1
1984	0	0
1985	0	0
1986	0	0
1987	1	1
1988	1	1
1989	3	3
1990	3	3
1991	11	13
1992	28	30
1993	67	78
1994	257	327
1995	780	1179
1996	968	1540
1997	1167	1816
1998	1120	1774
1999	1243	1906
2000	1267	2035
2001	1252	2138
2002	1321	2154
2003	1200	1905
2004	1098	1723
2005	1055	1663
2006	1013	1655
2007	1075	1705
2008	982	1575
2009	999	1551
2010	984	1524
2011	893	1339
2012	631	882
2013	333	439
2014	38	47

Source: This study

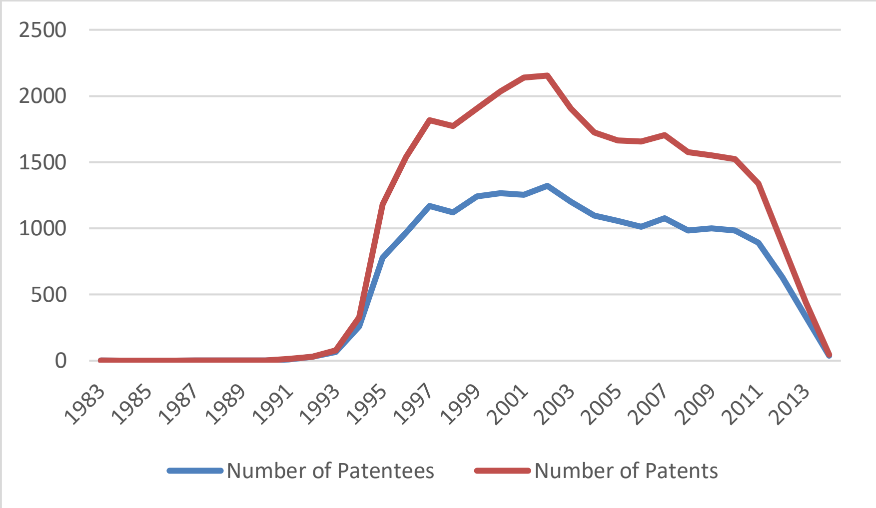


Figure 4: The Tendency of Filing Global Patents Each Year

Source: This study

Table 3: The Trends in the Number of Patents: Mainly from the Year Wherein the Patents Are Examined and Approved

Year	The number of applicants	The Number of the patents
1997	840	1266
1998	1020	1565
1999	1025	1657
2000	1132	1735
2001	1166	1788
2002	1189	1877
2003	1187	1800
2004	1064	1653
2005	917	1319
2006	931	1376
2007	868	1306
2008	804	1207
2009	836	1224
2010	1086	1813
2011	1172	1933
2012	1261	2134
2013	1526	2396
2014	1562	2629
2015	296	329

Source: This study

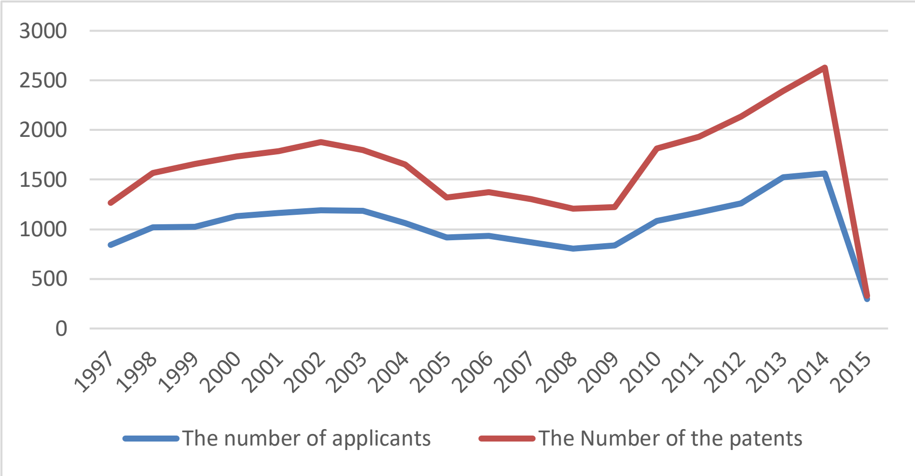


Figure 5: The Tendency That Global Patents Are Approved and Published

Source: This study

From the aforesaid tables and figures, it can be seen that during the two decades from 1993 to 2013, the number of approved patentees and patents were at a peak, which indicates that the organic silicon industry was booming. The number of patent approvals reached its highest in 2014. It is evident that in 2014, there were many groundbreaking breakthroughs in technological innovation of organic silicon.

5.2.1 Country-based Analysis

The relevant analysis was conducted based on major competitive countries to explore the development of organic silicon technology in various countries, including: analysis of the patents of the countries to which they belong, analysis of the share of patents in the countries to which they belong, and analysis of trends in the number of patents of the countries to which they belong.

Table 4: The Number of Global Patents That Main Countries Have

Ranking	Country	The numberof patents	The numberof applicants
1	US	16812	6387
2	JP	5916	1202
3	DE	2134	864
4	FR	1766	393
5	KR	524	194
6	TW	519	293
7	CH	423	170
8	CA	365	258
9	GB	315	251
10	NL	286	98

Source: This study

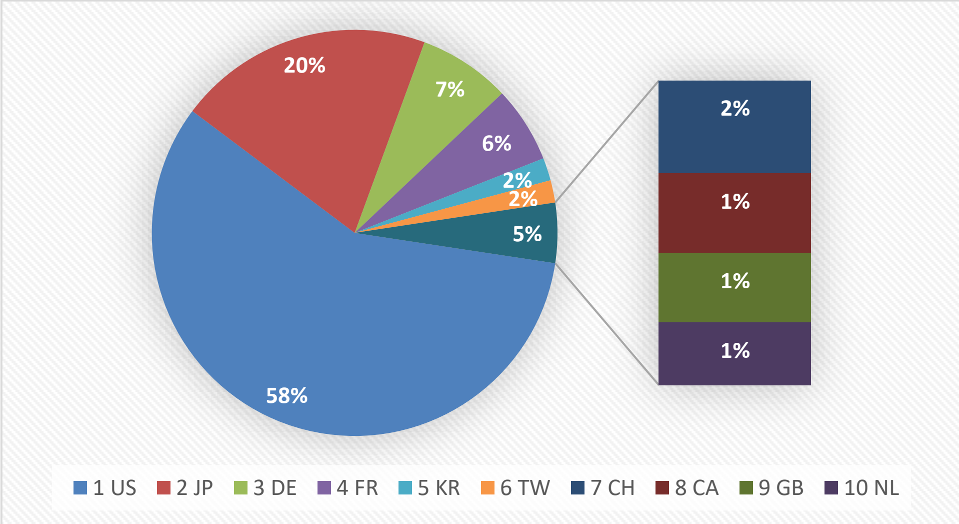


Figure 6: The Percentage of Global Patents of the Main Countries

Source: This study

The number of patents and occupancy of major rival countries is analyzed here. Based on the country to which the patentee belongs, the number of patent applications for organic silicon technologies and the distribution of the number of patentees in countries show that organic silicon has been highly developed in the United States. Japan is the only Asian country in the top five while Taiwan is the only one that does not have organic silicon upstream raw material producers among those major countries who are technologically advanced in the patent technology.

5.2.2Company-based Analysis

This study carries out analysis of various indicators on specific competitors with patent data, including detailed data of corporate R&D capabilities. The corporate share of patents will be used to analyze corporate R&D capabilities, and the detailed data of R&D capabilities will be used to interpret R&D information on company's investment in organic technology development. The data used to analyze the R&D include the number of patents produced by major companies, the duration of the case, the number of inventors involved, and the average age of patents. In this way, the manufacturers' competitiveness of organic silicon is evaluated. Thereby, one can know himself as well as knowing his competitors so as to win the battle.

Table 5: The Research and Development (R & D) Ability of the Companies

Name of companies	The number of patents	Activity period	The number of inventors	Average age of the patents
L'OREAL	551	19	487	11
DOW CORNING CORPORATION	414	19	730	10
PROCTER & GAMBLE COMPANY	361	19	863	12
SHIN-ETSU CHEMICAL CO., LTD.	482	19	545	8
L'OREAL S.A.	345	16	371	8

Note: The first five companies who have the highest R & D ability are analyzed here.

Source: This study organized result

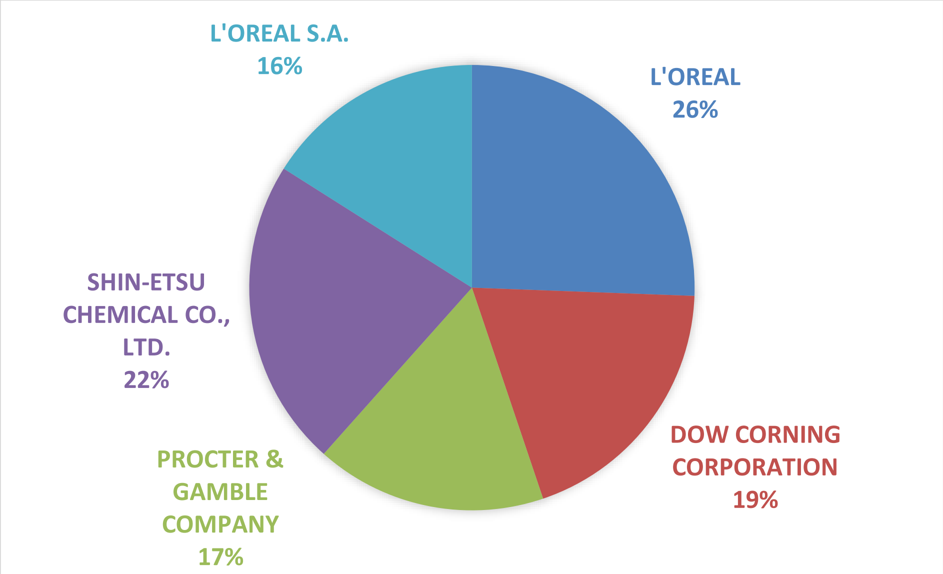


Figure 7: The Patent Percentage of Each Company

Source: This study organized result

The trend analysis of the number of corporate patents is conducted here. The number of patents that companies have over the years is used to analyze the trends of patent output in order to grasp the dynamics of a company's investment in organic silicon technology, gain insight into the company's patent portfolio in different years, and avoid inadvertent contact with important information such as technical landmines. The trend analysis of the number of patents is shown in Figure 8.

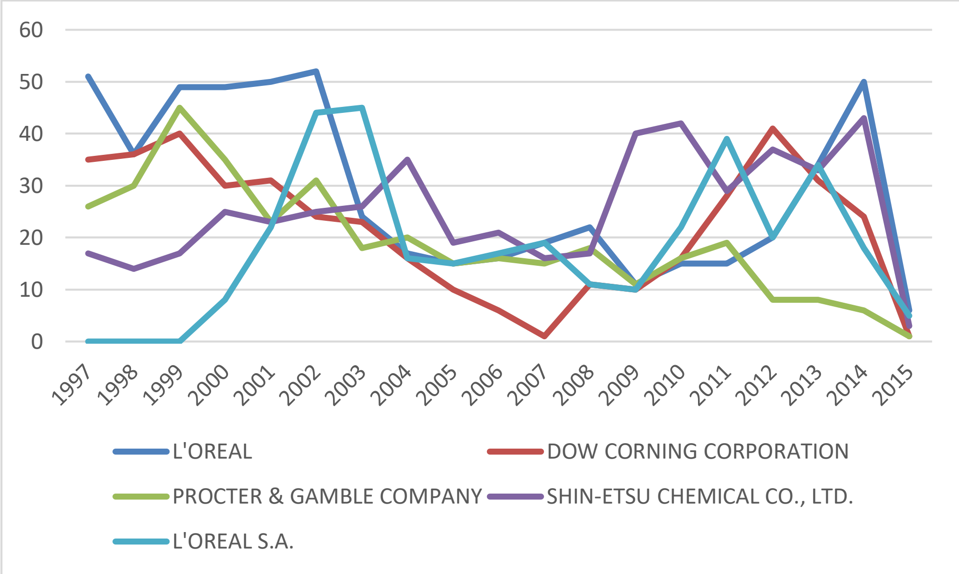


Figure 8: The Number of Global Patents That the Main Companies Filed Each Year

Source: This study organized result

According to the application status over the years, it can be found that the peak for the patent applications was from 1998 to 2003, which indicates that the technical field has begun to enter the stage of market sales at that time. Figure 8 also shows that the bottleneck of the organic silicon technology occurred from 2004 to 2009. The organic silicon technology experiences a positive growth from 2010 to 2015. It may represent a bottleneck, an improvement, or a trend of positive growth that may last in the near future.

VI. Conclusion

In recent years, China's total production and consumption of organic silicon materials enable it to form a new technology-intensive industry, which is important to its economic development. The Chinese government has included organic silicon in the "Twelfth Five-Year Plan" and "Thirteenth Five-Year Plan" as an industry to be encouraged to develop in 2013 and 2016, respectively. It not only plays an important part in one of the seven strategic emerging industries, but also constitutes an indispensable material for the industry. Organic silicon plays a decisive role in the emerging industry.

The organic silicon industry in Taiwan has not grown significantly. That is mainly because the Taiwan government has not noticed the drastic changes that organic silicon has produced in the global economic development. In Taiwan, upstream and downstream organic silicon manufacturing has a low level of links. Its overall technological level is significantly behind the advanced level in the world.

Apart from the obvious gap, organic patent applications are mainly concentrated in the multinational corporations. Taiwanese companies heavily depend on their key technologies, resulting in insufficient innovation and development of downstream products. That seriously affects the international competitiveness of Taiwanese companies in the organic silicon field.

In view of this, the Taiwan government must face up to the changes of organic silicon in the quality and quantity in the global industrial development. It is necessary for Taiwan to formulate specific development plans through production, government, study, and research, hoping to actively promote the innovation and development of the organic silicon industry in Taiwan. In this way, Taiwan may improve its position and competitiveness in the organic silicon industry across the world.

References

Abraham, B. P., and Moitra, S. D. (2001), *Innovation Assessment through Patent Analysis*, Technovation, Vol.21(4), pp.45-252.

Ai-Hsia Chang, Chin Chou, and Li Chen (2014). *Progress on Silicone Industry in Foreign Countries in 2013*, Silicone Materials, pp. 299-318.

Ashton W. B. and Sen R. K. (1988), *Using Patent Information in Technology Business Planning-I,* Research Technology Management, Vol.31(6), pp.42-46.

Barney, J.B. (1991), Firms resources and sustained competitive advantage, Journal of Management, Vol.17, pp.99-120.

Berkowitz L. (1993), *Aggression: Its Causes, Consequences and Control*, New York : Mcgraw-Hill.

Bommer, M. and Jalajas, D. S. (2004), Innovation Sources of Large and Small Technology-Based Firms. IEEE Transaction Engineering Management, Vol.51(1), pp.13-18.

Bosi Data Research Center (2011), *Report on the Market Supply and Demand and Investment Prospects of China's Silicone Industry 2011-2015*.

Branson, J. (1966), *Transfer Technology Knowledge by International Corporation to Developing Countries*, American Economics Review, May, pp.259-267.

Brian P. C. (2008), Data and the measurement of R&D program impacts, Evaluation and Program Planning, Vol. 31(3), pp.284-298.

Bushee, B.J. (1998), *The Influence of Institutional Investors on Myopic R&D Investment Behavior*, Accounting Review, Vol.73(3), pp.305-33.

Canto, J. G. D. and Gongalez, I. S. (1999), A resource-based analysis of the factors determining a firm's R&D activities, Research Policy. Vol.28, pp.891-905.

China Industry Insight Network (2014), *Prospects of China's Organic Silicon Industry*, http://www.51report.com/article/3054361.html.

Ching-Fang Li (2013), *What Is a QualitativeStudy?*, http://www.sheng-tsung.com /2013/02/04/.

Coad A. and Rao R. (2010), Firm growth and R&D expenditure, Economics of Innovation and New Technology, Vol.19(2), pp.127-145.

Cooper, R. S., and Merrill, S. A. (1997), *U.S. Industry: Restructuring and Renewal – Industrial Research and Innovation Indicators*, Washington, D.C.: National Academy Press.

Cyert, R.M. and J.G. March (1963), *A Behavioral Theory of the Firm*, NJ: Prentice-Hall.

Ettlie, J. (1998), *R&D and Global Manufacturing Performance*, Management Science, Vol.44 (1), pp.1-11.

Evngelista, R. and Savona, M. (2003), *Innovation, employment and skills in services: Firm and sectoral evidence*, Structural Change and Economic Dynamics, Vol.14, pp.449-474.

Furman, J. L., Porter, M. E., and Stern, S. (2002), *The determinants of national innovative capacity, Research Policy,* Vol.31(6), pp.*899-933.*

Galende Del Canto, Jesús and Suárez-González, Isabel. (1999). *A Resource-Based Analysis of the Factors Determining a Firm's R&D Activities*, Research Policy. Vol.28, pp.891-905., 10.1016/S0048-7333(99)00029-3.

Grupp, G., and Schmoch, U. (1999), *Patent statistics in the age of globalization: new economic interpretation*, Research Policy, Vol.28(4), pp.377-396.

Guan J.C. ET AL. (2008), *Innovation strategy and performance during economic transition: Evidences in Beijing*, China, Research Policy, Vol.38(5), 802-812.

Hsiao-Lin Wu (1998), *Patent Management Facilitates Technological Development. Master of Patent Management*, Taipei: Science and Technology Law Institute, pp.3-7.

Hsiao-Yung Yang (2009), *Industry Chain of Silicon and Circular Economy*, pp. 220-224.

Hsin-Ping Pu (2011), *Status and Forecasting of Silicone Industry in China*, Silicone Material, Vol.25 (5), pp.333-342.

Hung-Chiang Pai (2014), *The Core Issues of 13th Five-Year Plan for China's Silicon Industry*, China Chemical Industry News, November of 2014.

John Wong (2012), *The Emerging China—Centric East Asian Economic Order*, Asia-pacific Economic Review, Vol.5, pp.3-6, 11.

Lau, R. S. M. (1998), *How Does Research and Development Intensity Affect Business Performance?*, South Dakota Business Review, Vol.57(1), pp.4-8.

Lee, I.H. and Marvel M.R.(2009), *The moderating effects of home region orientation on R&D investment and international SME performance: Lessons from Korea* , European Management Journal, Vol.27(5), pp.316-326.

Mogee M.E. (1991), *Using patent data for technology analysis and planning*, Research Technology Management, Vol. 34, No. 4, pp. 43-49.

Pavitt K. (1988), *Uses and Abuses of Patent Statistics*, Handbook of Quantitative Studies of Science and Technology (edited by Raan V.), Amsterdam: Elsevier Science Publishers.

Schumpeter, J.A. (1942), *Capitalism, Socialism and Democracy*, New York: Harper and Brothers.

Shan-Yao Wu and Chih-Chieh Hsiao (2012). *Using Patent Analysis to Explore the Development Trend of Golf Club Industry in Taiwan*, Journal of Global Business Operation and Management, Vol. (4), pp. 83-94.

Sheng-Tsung Hou, and Mu-Yen Hsu (2013). *Accumulation and Interaction of Intellectual Capitals: A Case Study of Technology-driven Service Company*, Management Review, Vol.32(4), pp.81-101.

Sheng-Yu Feng, Chieh Chang, and Mei-Chiang Li (2004), *Organic Silicon Polymers and Their Applications*, Chemical Industry Press, pp.1-12.

Ta-Jen Chen, Mu-Hsuan Huang (2009), *Patent Information Retrieval, Analysis, and Strategy*, Taipei: Hwa Tai.

Teece D.J. (1986), *Profiting from Technological Innovation: Implications for Integration, Collaboration, and Licensing, and Public Policy*, Research Policy, Vol.15(6), pp.285-305.

Tsai, K. H. and Wang J.C. (2004), *The R&D Performance in Taiwan's Electronics Industry: A Longitudinal Examination*, R&D Management, Vol.34 (2), pp.179-189.

Wan-Ying Lin, Jui-Chih Wang, Shun-Ho Yu (2012), *R&D, Insider Board Members and Firm Performance*, Review of Accounting and Auditing Studies, Vol.2(1), pp.61-90.

Yoon J.Y. and Kim K.S. (2012), *Trend Perceptor: A property-function based technology intelligence system for identifying technology trends from patents*, Vol.39(3), pp.2927-2938.

Yu-Cheng Chen (2011), *Present Situation of Silicone-related Industry in the World and Mainland China*. Industrial Materials, pp.126-133.

Yu-Chi Shao (1995), *Tools for Industrial Upgrading—Patent Map*, CCL Technical Journal, Vol.37, pp.60-68.