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從專利角度探討晶圓代工廠與半導體整合元件廠之角色與技術定位

Positioning and shifting of character and technology for Foundries and integrated device manufacturers by patent perspectives

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致謝

在職場工作十多年之後，又重拾書本回校園攻讀博士學位，以一圓我從小的博士夢。在博一及博二的主要修課期間新竹台北兩地跑，特別在工作氣氛相當緊張忙碌的半導體產業裡，持續的毅力是不可或缺的。

本論文之得以順利完成，最要感謝的首推指導教授陳達仁老師及黃慕萱老師，其謙謙儒雅風範，浩浩學術涵養，授業門下，如沐春風。他們在學業與工作上給予我相當大的時間彈性及研究方向的自主性，並隨時在研究的關鍵處指點了我，讓我的研究更為順利。此外，口試委員們亦多所指導，提供給我做研究的不同方向，不勝感激。

此外，這六年攻讀博士班期間許多同窗是我修課上的好夥伴，而在寫作與投稿論文期間，俊傑對於數據的收集以及蕙茹和薇慈在論文的潤稿及回覆的協助，對於我的研究幫助頗大，而我回報的卻很少。

我在台積電及采鈺科技的工作夥伴與長官讓我在繁忙的工作中還能有餘裕於學業與研究的進行。我的妻子全心全意地照顧小孩，讓我可以毫無後顧之憂的衝刺工作與學業。我的父母對於我同時工作與學業兩頭忙，時時提醒我注意身體，對於年紀已漸年邁的他們，我是點滴在心頭。

離開校園十七年之後，終於取得學術界最高學位-博士，著實來自於許多人的協助與關懷。願以此論文與所有幫助過我的人共享。

摘要

整合元件廠與半導體代工廠是半導體供應鏈中非常主要的兩個角色。過去的三十年，整合元件廠與半導體代工廠的關係已出現了變化，也就是越來越多的整合元件廠不管是公開或私下已轉型成為半導體代工廠。在 1981 至 2010 年間，我們從專利的角度討論技術上半導體供應鏈的角色演變並檢視特定整合元件廠在生產力、品質及整合性等指標在技術焦點的表現。半導體代工廠已逐漸從單純的生產產能提供者轉變為兼具技術的移轉者，並且已同時在晶圓製程技術及晶圓設計應用技術等兩方面技術領域具備影響力。相對地，過去被認為是技術主要提供者的整合元件廠逐漸面臨挑戰。除了從整體產業的觀點外，我們也從技術焦點的層面去分析特定整合元件廠的技術領域定位及演變。研究結果亦發現:超微(AMD)已從原為單純整合元件廠的角色轉而將其晶圓工廠獨立成立一個半導體代工廠，為其中最顯著的例子，而它技術定位是位於以半導體代工廠為主的區域。並且美光(Micron)及德州儀器(TI)儘管未正式宣佈進入半導體代工市場，但它們的技術定位也是位於以半導體代工廠為主的區域，可見當它們如想轉入半導體代工市場時是具備競爭力的。

關鍵詞：整合元件廠; 半導體代工廠; 晶圓製程技術; 晶圓設計應用技術; 技術焦點

Abstract

The integrated device manufacturers (IDMs) and contract chip makers (foundries) are two major characters in the semiconductor industry value chain. The relationship between IDMs and foundries has changed over the past three decades. Increasing number of IDM companies have diversified or branched off as foundry companies, whether officially or privately. In this Dissertation, we attempts to discuss patterns of characters' shifting in technology and explore the technology focus of IDM companies and the shifting of that focus by examining the shifts in focus of productivity, quality, and integrated measurement of selected IDM companies between 1981 and 2010 by patent perspective. Foundry has gradually become the technology transferor rather than purely the manufacturing capacity provider. Foundry's impact on the technology level has risen steeply on both the wafer process technology fields and the wafer design application technology fields. As a result, IDM, traditionally considered the primary technology contributor in the semiconductor value chain for the past 30 years, will continue to be challenged in the semiconductor industry. In addition to the industry's point of view, the results of this research reveal that AMD, one of the more notable companies to have established a pure foundry company from an IDM company, is located in the foundry-oriented area. Additionally it shows that, although Micron and TI have not officially announced their intentions to diversify or branch off as foundry companies, the two are located in the foundry-oriented area as a means of showing their competitive positions with regard to joining the foundry business.

Keywords: IDM; Foundry; wafer-process technology; wafer-design application technology; technology focus

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Chapter 1

Introduction

1.1 Background

The semiconductor industry has been one of the most important industries over the past three decades. Due to the wide applications of semiconductors to products in telecommunications, computers, and consumer electronics, the semiconductor industry has all but become a core upstream element every part of the electronics industries. The three major categories in the semiconductor main supply chain: Design House, IC circuit design and sales (like Qualcomm, Broadcom, and NVIDIA); Foundry, providers of contract chip fabrication (like TSMC, UMC, and GlobalFoundry); and IDMs, integrated device manufacturers for overall semiconductor industry integrators (like Intel, Samsung, and IBM) in Fig. 1.1. Traditionally, IDM is regarded as a technology leader and contributor, whereas Foundry is considered only a manufacturing capacity provider. Design House is dedicated to IC circuit design and sales. Categories in the industry have changed in the main semiconductor industry value chain over the past 30 years, especially IDM. The relationships among Design House, Foundry, and IDM have changed especially Foundry and IDM. That is, the relationship between Foundry and IDM has changed from cooperation to competition to some extent. The concept of co-opetition refers to the relationship between firms that simultaneously embraces both competition and cooperation (e.g., Brandenburger & Nalebuff, 1996). Thus, the concept of co-opetition comprises a complex combination of two opposite logics of interaction: the competitive model, assuming that companies interact based on conflicting interests, and the cooperated model, asserting that companies interact based on common interests in a certain area (Bengtsson & Kock, 2000; Cassiman et al., 2009). In spite of many risks and conflicts, co-operation with competitors is usually driven internally by the need to share R&D or production risks and costs, by the goal to pool resources, develop and expand markets together, address major technological challenges, and realize synergistic effects (Das & Teng, 2000; Huang et al., 2009), or externally by the requirement to comply with new regulations (Nakamura, 2003). There are certainly many reasons for this change, including financial problems, manufacturing capacity, and geographical clusters (Ernst, 2005).

To examine the character shifting in technology, we used patent analysis techniques as the quantitative basis for this study. After explored the character shifting of the semiconductor industry value chain, we also tried to further detect the positioning and shifting of technology focus for IDM. From the technology focus's point of view, we provided a integrated measurement to evaluate the change for specific IDM companies. The strategy decision makers or technology officers of companies could apply the methodologies to detect their own position and competitors' position to take necessary actions. Patent count and patent citations have been used to evaluate knowledge dissemination and transfer processes in R&D, as well as research productivity and research impact (Narin, 1994). Since the assignees need to refer to other related patent to prove theirs patents importance, it is meaningful to evaluate the patent value by the index. Lewison (1998) assessed the impact of funding sources on gastroenterology research in the UK using patent analysis. Huang et al. (2003) analyzed the longitudinal change of the international landscape of nanometer scale science and engineering (NSE) research and development based on information collected from the United States Patent and Trademark Office (USPTO) database. The following are the reasons that we selected the USPTO as the patent database. Approximately half of the inventions of U.S. patents are foreign-owned, and each country's invention patents in the U.S. are roughly proportional to their country's Gross Domestic Product (GDP) (Narin, 1991). Taking geographical factors into consideration, the USPTO patents provide detailed address information of assignees and inventors that are essential to analyze geopolitically-related collaboration. For other patent data sources, some have small foreign-owned patent shares, such as the State Intellectual Property Office of P.R.C. (SIPO), which has only 8% issued foreign-owned patents in 2011 (SIPO, 2012). Some sources lack detailed address information for assignees and inventors in patent text content. Thus, the USPTO is the most appropriate source to analyze relative researches. In addition to the selection of the patent database, there are some limitations for the patent statistics in the research. For example, the appearance of an absolute decline in inventive activity was largely a statistical mirage, caused by a bureaucratic rather than an economic or technological cycle (Griliches, 1990). Meanwhile, patent rights increasingly become bargaining chips in the patent portfolio races **(**Hall & Ziedonis, 2001). In addition to the above limitations for using patent data as analysis tool, the link between patent quality and value in cumulative innovation is also weak (Baron & Delcamp, 2010). That is, more and more strategic thinking is used for the patent information especially in complex technologies. It will somehow impact the effectiveness for the research result by patent perspectives.

The status of research and development in high-tech electronic companies of Taiwan were explored based on their published patents (Huang, Chiang & Chen, 2003). Patent citation information can be used to represent knowledge transfer (Karki, 1997; Oppenheim, 2000), as previous studies have done. For example, the inter-organization patent citation patterns of defense-related research and development were analyzed in the civilian sector (Chakrabarti, Dror

& Eakabuse, 1993). Chen and Hicks (2004) studied the interactions between academia and industry by analyzing the paper-patent citations in the field of tissue engineering. Patents in the fields of biotechnology and information technology were explored via the geographic distribution of scientific research's impact (Verbeek, Debackere & Luwel, 2003). Singh (2003) explored the impact of inventors' social distance on the knowledge flow within USPTO patents. These knowledge diffusion studies were based on the citation patterns between entity pairs.

Generally speaking, IDMs play an integration character—designing, manufacturing, and selling—in the semiconductor industry and Foundries provide IDM and Design Houses with manufacturing capacity. In the early stages of the development history of the semiconductor industry, IDMs dominated the entirety of the industry's development of technological capability and manufacturing capacity. Due to IDMs' integration character in the semiconductor value chain, they can diversify or shift their character in the semiconductor value chain toward either Foundries or Design Houses. In short, IDMs may, to some extent, be competitors of Design Houses or Foundries. In fact, over the past decade, increasing number of IDM companies have claimed positions in the foundry business or taken the "Fab-Lite" strategy to ease financial burdens. Compared with IDMs, Foundries and Design Houses have retained their current characters in the semiconductor value chain. There are many reasons for IDM companies to shift their technology focus, such as financial problems, manufacturing capacity, and geographical clusters. With regard to development trends in the semiconductor industry, Ernst (2005) discussed the growing geographic mobility of chip design and its dispersion in Asia. He argued that, to cope with such demanding requirements, firms must have a strong incentive to concentrate on innovation in their home countries. For capacity planning, many IDM companies or Design Houses commonly suffer from foundry capacity shortages when the industry is prosperous. A method that accepts this uncertainty of demand and uses stochastic integer programming to find a tool set responsive to shifts in demand was presented by Hood et al. (2003), who considered a set of possible discrete demand scenarios with associated probabilities, determined the tools to be purchased, and minimized the weighted average unmet demand under a budget constraint. The semiconductor industry is highly capital-intensive, so it would be natural to apply the strategic alliance approach to the technology development. To provide value-added directions and information to semiconductor companies that want to select partners for R&D cooperation among different characters and technology fields, character shifting is one of the most important factors to consider. Character shifting may also attract researchers to explore semiconductor technology shifts within characters. Most research into the shifting of or relationship among these characters has focused on economics, manufacturing capacity, and strategy management. Regarding technology position, Debackere et al. (1999) explored regional technological capabilities, linked technological position to economic growth, and found a competitive advantage in European patent data. Research into corporate technology strategy that secures competitive positions by patent analysis was also discussed in this research (Ulrich, 2009). Patent data are a valuable source of information for technological development. Because they contain standardized data relating to new ideas and technological developments and are available to all, patents have been treated as the most important output indicators of innovative activities (Frietsch & Grupp, 2006) and patent data have become the focus of many tools and techniques used to measure innovation (Belderbos, 2001; Pilkington, 2004; Hanel, 2006). Patent analysis is widely applied to the exploration of competitive advantages among companies or industries. Henderson and Cockburn (1994) attempted to measure heterogeneous organizational competence using patent data in pharmaceutical research. Fleming and Sorenson (2001) demonstrated that technology should be considered a complex adaptive system based on patent data. Several researchers, such as DeCarolis & Deeds (1999) and Gittelman & Kogut (2003), conducted empirical studies using patent and financial data from biotechnology firms. Long (2002) regarded patents as a signaling mechanism by which technology firms can credibly publicize information. Daim et al. (2006) explored forecasts in three emerging technology areas by integrating the use of bibliometrics and patent analysis into well-known technology forecasting tools such as scenario planning, growth curves, and analogies. The aforementioned literature measured innovation activities or explored the technology development in various industries. However, little research focuses on the detection of position and the position shifting of technology focus in a specific industry. In addition to previous applications, we applied the framework to detect messages delivered by selected IDM companies concerning the shifting of technology focus.

There are many definitions on technology (Floyd, 1997; Whipp, 1991; Steele, 1989). Examination of these definitions highlights a series of factors that characterize technology, which can be considered as a specific type of knowledge (although this knowledge may be embodied within a physical artifact, such as a machine, component, system or product). The major feature of technology that distinguishes it from more general knowledge types is that it is applied, focusing on the know-how of the organization. While technology is usually associated with science and engineering ('hard' technology), the processes that enable its effective application are also important—for example, new product development and innovation processes, together with organizational structures and supporting knowledge networks ('soft' aspects of technology). Treating technology as a type of knowledge is helpful, as knowledge management concepts can be useful for more effectively managing technology (Stata, 1989; Nonaka, 1991;

Leonard-Barton, 1995). For instance, technological knowledge generally comprises both explicit and tacit knowledge. Explicit technological knowledge is that which has been articulated (for example in a report, procedure or user guide), together with the physical manifestations of technology (equipment). Tacit technological knowledge is that which cannot be easily articulated, and which relies on training and experience (such as welding or design skills). Similarly, there are many definitions of technology management in the literature (Roussel et al. 1991; Gaynor, 1996). For the purposes of this paper the following definition is adopted, proposed by the European Institute of Technology and Innovation Management (EITIM): Technology management addresses the effective identification, selection, acquisition, development, exploitation and protection of technologies needed to achieve, maintain a market position and business performance in accordance with the company's objectives.

This definition highlights two important technology management themes:

1. Establishing and maintaining the linkages between technological resources and company objectives is of vital importance and represents a continuing challenge for many firms This requires effective communication and knowledge management, supported by appropriate tools and processes. Of particular importance is the dialogue and understanding that needs to be established between the commercial and technological functions in the business.

2. Effective technology management requires a number of management processes and the EITIM definition includes the five processes proposed by Gregory (1995): identification, selection, acquisition, exploitation and protection of technology. These processes are not always very visible in firms, and are typically distributed within other business processes, such as strategy, innovation and operations.

Technology management addresses the processes needed to maintain a stream of products and services to the market. It deals with all aspects of integrating technological issues into business decision making, and is directly relevant to a number of business processes, including strategy development, innovation and new product development, and operations management. Healthy technology management requires establishing appropriate knowledge flows between commercial and technological perspectives in the firm, to achieve a balance between market 'pull' and technology 'push'. The nature of these knowledge flows depends on both the internal and external context, including factors such as business aims, market dynamics, organizational culture and technological context.

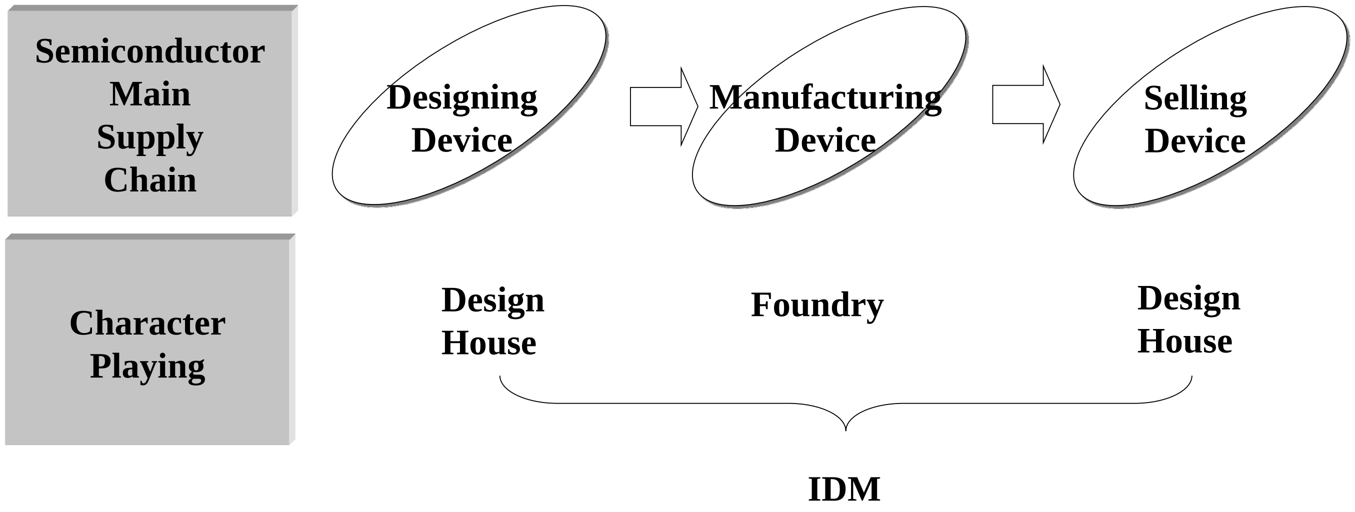


Fig.1.1: Semiconductor main supply chain vs. character playing

1.2 Motivations, Purposes, and Hypotheses

Traditionally, IDM is regarded as a technology leader and contributor, whereas Foundry is considered only a manufacturing. The purpose of the research aims to explore the technology development shifting between IDM and Foundry. First, what we want to examine whether IDM companies dominate technology development still. Secondly, we would like to study any hints existing for the character shifting in the semiconductor industry. Finally, we want to build a strategic map to detect the position and position shifting for the character and technology focus for self and competitors.

Many researches have explored companies' technology positions as a means of monitoring and understanding their technological strength. This information will usually be provided to the decision makers of a company as a means of internally managing their technology. On the other hand, company stakeholders, such as shareholders and analysts, have an increasing interest in assessing a company's technological competence because of its strong impact on a company's future competitiveness (Ernst, 2003; Bowonder et al., 2000). Position and the shifting of technology focus of specific companies or industries is important strategic information for decision makers of companies, and could be used to detect their relative technology levels in the industry. In addition to industry practitioners, industry researchers could also apply the information as a means of grasping the technology shifting in specific industries. This study aims to provide decision makers of companies with the overall position of technology focus for specific IDMs. By using the position map created from this study, decision makers can detect their relative technology levels within the industry. This study also aims to explore the shifting of technology focus for specific IDMs. The decision makers of companies or industry researchers could apply the shifting map created in this study to detect the character shifting for specific companies or industries while still in the early stages.

The positioning and position shifting of technology focus help monitor the overall competitiveness or cooperation possibilities for decision makers of R&D or management teams in the IDMs. Moreover, decision makers could apply the information gleaned to monitor the shifting of targeted companies or industry while still in the early stage. Hence, we apply a patent analysis for the detection of positions and position shifting of technology focus for IDM companies.

From the technology point of view, we attempted to apply patent activity, patent quality, and the combination of patent quality and relative patent activity share to study the shifting of characters in the semiconductor industry value chain during different technology eras. The traditional hypotheses of the characters in technology in the semiconductor value chain are as follows. (1) IDM is a technology giant, in both technology activity and technology quality among characters in the semiconductor industry. (2) Foundry excels only at wafer process patents but is not as successful at wafer design application patents. (3) The wafer design application patents and the wafer process patents are regarded as the so-called “Pull” patent type and “Push” patent type, respectively. The traditional hypotheses above will be clarified through the study.

1.3 Contributions

In the course of this research, we have achieved three major findings that constitute integrated measurement for the shifting of character and technology focus in the semiconductor industry.

The first finding is that Foundry companies are becoming technology transferors rather than merely manufacturing capacity providers. Categories in the semiconductor industry value chain have changed with different technology eras, especially for IDM and Foundry. From the technology point of view, we completed the patent analysis for different categories in different wafer size eras. It was found that patent activity increased clearly from the 6- and pre 6-inch wafer technology era to the 12-inch wafer technology era. IDM unarguably dominated the top ranking in patent activity, but performed more weakly in patent quality. Instead, Design House and Foundry out-performed IDM, especially in the latest 12-inch wafer size era.

The second finding is derived from the first one. We continued to explore the technology capabilities for IDM and Foundry by patent perspectives. In addition to industry level, we also studied the insights to specific companies. We targeted patents in the semiconductor industry, including IDMs and Foundries, from the major technology fields over the past three decades. These technology fields are classified as wafer-design application patents or wafer-process patents. We apply the wafer-design patents instead of IC-design patents due to the focus for wafer related patents. Wafer-design application patents include electronics communication, computer software and hardware, and digital information storage; wafer-process patents include semiconductor making or forming, semiconductor manufacturing, semiconductor package, active solid-state devices, and chemistry. To provide a base for comparison, we also explored the technology focus positions for overall Foundry companies and the shifting of that focus, averagely aligned with relative research methods.

IDMs are located at wafer-design application technologies during the targeted period (1981-2010). On the other hand, the technology focus of Foundries is on wafer-process technologies.

The third finding, a positioning map of competitive analysis by patent perspectives, is constructed by two dimensional methodologies. It is our aim to explore the positioning and shifting which was detected for the selected IDM companies from the technology focus perspective. To express the productivity and quality of technology focus for the selected IDM companies simultaneously, we designed combination charts with productivity/quality on design-wafer application technologies and wafer-process technologies as the X-axis/Y-axis respectively.

1.4 Summary of Applicability

The findings above are applicable to those who make the technology development and technology character decisions in companies. It could provide a comprehensive picture for detecting relative competitiveness between their company and its competitors (or the industry average) in the semiconductor industry. For industry researchers, this study could be applied to other industries to detect the overall picture of the corporate business decisions of targeted companies in the early (development) stage through patent analyses. This study detected the position and positions shifting of technology focus for the selected IDM companies from patent perspectives.

Chapter 2

Literature Review

Generally speaking, the character shifting of industry, especially in high-tech industries, has been the mainstream for large scholarly literatures during the past 3 decades. Many of these researches argued that industries evolve through a process of vertical integration, characterized by the control by different firms of the phases of an industry value chain, such as research and development, manufacturing, and marketing, rather than being vertically integrated within the boundaries of individual firms. The limited theoretical and conceptual literature on this process typically treats vertical specialization as a structural feature of industries that are relatively "mature," but rarely considers the influence of firm actions on the shifting of industry structure. Vertical integration is also termed vertical disintegration, and often is related to the entry of specialist firms into distinctive segments of the vertical value chain. In some examples, vertical specialization may span international boundaries and give rise to complex international production networks. Although the discussion that mature industries develop a vertically specialized structure dates back to Stigler (1951) who in turn credited Adam Smith with the elementary concept, the factors underpinning this structural trend, as well as the extent to which vertical specialization accurately describes industry shifting, have received little attention. The semiconductor industry is "disintegrating" vertically, separating product design from manufacturing. Traditionally, semiconductor manufacturing is contributed in Asia and design specialists and R&D remain concentrated in US, Europe, and Japan. Since more and more resources are put for Foundry business, the situation has changed. Foundries have gradually transformed from technology acceptors to donators. To explore the relationship and shifting among IDM, Foundry, and Design House, we strengthen the discussion for the development history of semiconductor industry by following sections. Meanwhile, we also interpret the co-opetition behavior further for the semiconductor industry value chain.

For the first two decades of the semiconductor industries, large integrated producers such as Intel and IBM designed their own solid state components, manufactured the majority of the capital equipment used in the production process and utilized internally produced components in the manufacture of electronic computer systems that were leased or sold to their customers (Braun & MacDonald, 1978). During the late 1950s, commoditized manufacturers entered the U.S. semiconductor industry and gained market share at the expense of firms that produced both electronic systems and semiconductor components. Specialized producers of semiconductor manufacturing equipment began to appear in the industry by the early 1960s.

The strong relationship between product design and process innovation (Pisano, 1997) that existed during this period meant that leading firms developed their product and process technologies internally, relying heavily on firms specific, tacit know-how. For past 15 years, the interdependence between product design and process development has weakened considerably in many semiconductor product fields. The weaker interdependence has enabled specialist firms to enter into the design (and marketing) of semiconductor devices, and other specialists to enter the manufacture of semiconductor devices meeting the design specifications of these Design House and others. Entry by specialized firms has further weakened the formerly strong links between process and product development in some product lines, thereby accelerating the trend.

Hundreds of Design House that design and market semiconductor components have entered the global semiconductor industry since 1980. These firms rely on contract manufacturers (so-called “foundries”) for the production of their designs. Design House serve a variety of fast growing industries, especially computers and communications, by offering more innovative designs and shorter delivery times than integrated semiconductor firms. Design House’s share of global semiconductor industry revenues has grown from a negligible amount in 1989 to almost 12% of the industry by 2002. During the past five years, Design House revenues have grown at a 15% compound annual growth rate, compared with a 1% growth rate for overall semiconductor industry sales (Arensman, 2003).

Foundries, by contrast, specialize in semiconductor manufacturing and provide customized manufacturing capacity. The group includes Foundries, as well as the foundry subsidiaries of some established integrated semiconductor manufacturers seeking to utilize their excess fabrication capacity. To increase vertical specialization in the global semiconductor industry has resulted in the entry of numerous new firms and has been associated with significant geographic redistribution in production capacity.

2.1 Integration in Process and Product Development

The growth in integration for the semiconductor value chain since 1985 reflects the influence of both market wise and technology wise factors. The market expansion for semiconductor devices enabled vertically specialized semiconductor design and production firms to exploit economies of scale and specialization, consistent with the predictions of Stigler and Smith. Scale economies lowered production costs, expanding the range of potential end-user applications for semiconductors and creating additional opportunities for entry by vertically specialized firms. The huge capital requirements of semiconductor manufacturing provided another impetus to integrate each character, since these higher fixed costs made it necessary to produce large volumes of a limited array of semiconductor components in order to achieve lower unit costs. The design cycle for new semiconductor products also has become shorter and product life cycles more uncertain, making it more difficult to determine whether demand for a single product will fully utilize the capacity of a fabrication facility that is devoted exclusively to a particular product and increasing the risks of investing in such dedicated capacity. Since Foundries are able to provide complicated product mix simultaneously, they are less exposed to these financial risks.

The emergence of integration for semiconductor industry value chain has been facilitated by at least three technological factors. Through a process of competitive selection played out over several years, manufacturing technologies have converged on standardized Complementary Metal Oxide Semiconductor (CMOS) processes for the manufacture of mainstream digital products. The emergence of this process standard has facilitated the division of labor between product designers, who are able to operate within relatively stable design rules, and process engineers working to incrementally improve new process technologies (Macher et al., 1999). That is, two major technology focuses are divided by wafer-design application and wafer-process. Significant improvements in design software for the layout and simulation of novel semiconductor products have increased the computer-simulation capabilities available to product designers for evaluating the performance of novel circuits prior to production. Powerful electronic design automation tools and cell libraries also support the design of more complex chips. A final factor supporting greater vertical specialization within the industry is the entry of specialized providers of semiconductor designs and EDA software, as well as systems houses that compete in the provision of patent design blocks and system-on-chip (SOC) technology, licensing their designs for specific parts of a semiconductor device. Revenues associated with licensing, royalties and service/maintenance in markets for IP blocks and design cores have grown to $933 million in 2002 (Clarke, 2003).

Other technological innovations have also contributed to vertical specialization in the semiconductor industry. The “open-standards” PC architecture that was the fastest-growing market for semiconductor components during the 1980s and 1990s created standardized interfaces among components (see below), which in turn facilitated the specialized production of individual components and vertical specialization in component design. This pattern of vertical specialization seems entirely consistent with the “extent of the market” predictions of Stigler and Smith. The advent of partially programmable semiconductor devices now allows semiconductor designers to incorporate increasing levels of functionality onto devices (system-on-a-chip technology) without sacrificing the applications flexibility required of a true “systems” product. Advances in computer-aided design (CAD) software and tools, as well as high-bandwidth digital communications networks, also facilitate the exchange of huge amounts of data among design specialists and between Design House and manufacturing foundries.

At the same time, however, Macher (2004) stated that a number of large semiconductor firms remain integrated into both semiconductor device design and manufacture, and are now referred to as “Integrated Device Manufacturers” (IDMs). The advantages of integrated management of design and manufacture appear to be greatest in product lines at the leading edge of semiconductor technology, especially in DRAMs. In these areas, the demanding requirements for close coordination of design and process innovation mean that intra-firm management of these activities provides advantages in flexibility, responsiveness, and the trouble shooting for new manufacturing methods. Demand growth and larger markets thus appear to be necessary conditions for the success of vertical specialization in semiconductors, but they are by no means sufficient.

Since the timing and profile of these technology transfer channels differ somewhat from the chemical industry, vertical integration in the semiconductor industry has been associated with expanded licensing and inter-firm transfers of technology. During the 1970s and 1980s, U.S. IDMs were important sources of product and process technologies for less advanced semiconductor firms in Japan and South Korea, while U.S., Japanese and European IDMs supplied process and product technologies to Taiwanese and Singaporean foundry firms during the 1980s and 1990s. Many IDMs established relationships with foundries during the semiconductor market boom of the late 1990s, providing process technologies to foundries in exchange for guaranteed wafer supply. The development of a robust semiconductor intellectual property (IP) market also has spurred growth in the number and importance of specialized design firms. In some contrast to the chemical industry, however, product and process licensing in the semiconductor industry has facilitated entry by both vertically integration firms.

2.2 Regional Differences for Character Playing

Although regional specialization by product and stage of the manufacturing process has characterized the semiconductor industry for most of its history, the growth of foundry production has extended these trends. Since the early 1980s, roughly 85% of packaging and testing capacity in the semiconductor industry has been concentrated in Southeast Asia (Leachman & Leachman, 2001). Since the capital investment requirements for packaging and testing are roughly one-tenth those of wafer fabrication, however, the networks developed around these activities involve much more modest flows of investment than the more recent expansion of fabrication capacity.

Wafer fabrication capacity in the global semiconductor industry grew at an average rate of 36% per year during 1980–2001 (Leachman & Leachman, 2001). Growth in overall capacity was combined with the retirement of substantial amounts of “mature” capacity, reflecting the effects of rapid technological change. Since much of the investment in new capacity occurred in Southeast Asia and much of the retirement of capacity occurred in Japan and North America, the regional distribution of semiconductor manufacturing capacity has shifted considerably over the past 20 years. The North American and Japanese shares of global semiconductor production capacity fell significantly during 1980–2001, while the share attributable to “Asia/Pacific” has substantially increased (Leachman & Leachman, 2001), reflecting significant net expansion in capacity in Taiwan, South Korea and Singapore.

A reclassification of manufacturing capacity by region of ownership rather than location reveals a slightly different geographic pattern. Although Southeast Asian firms still account for the largest share of fabrication-capacity ownership, they are followed closely by North American producers (Leachman & Leachman, 2001). This pattern reflects the relocation of wholly-owned production capacity by North American, Japanese, and European firms to Southeast Asia since the mid-1990s. Southeast Asian firms, on the other hand, have tended to invest primarily within their home regions during this period.

The growing concentration of manufacturing capacity in Southeast Asia in general and Taiwan in particular is attributable in large part to the success of the foundry business model. Leachman and Leachman (2001) indicate that foundries’ worldwide fabrication capacity has risen from 8% in 1990 to nearly 25% by 2001, with foundries supplying roughly 75% of the worldwide foundry market and IDMs accounting for the remainder. Foundry revenues represent a growing portion of overall industry sales and approached $10 billion in 2000 (McClean, 2001). Pure-play foundries' manufacturing capabilities still lag those of the most advanced integrated manufacturers in Korea, Japan and the United States, but this gap has narrowed and continues to do so (Macher et al., 1998).

Although semiconductor manufacturing has become a more global enterprise, semiconductor design activities remain heavily concentrated within North America. A number of factors help explain North American dominance of semiconductor product design. Established regional high-technology clusters in areas such as Silicon Valley and Austin, Texas attract large numbers of product designers. These centers are often located near universities and other research centers that produce new design techniques and engineering talent. The role of U.S. universities in developing new design software and chip architectures has long outstripped their role as a source of new manufacturing methods, in part because the cost of constantly re-equipping the necessary facilities exceeds the resources of most academic institutions.

Design House remain concentrated in North America, although nearly 1,000 Design House are operating in two dozen countries outside of this region. Most of the non-U.S. Design House are relatively small in global terms, but Table 2.1 suggests that several non-U.S. concentrations of design expertise, largely made up of Design House, have emerged, mainly in Israel, Taiwan and Great Britain. Many of these non-U.S. Design House companies represent North American foreign design centers, but roughly half are from companies based outside the United States and Canada. Many of these non-North American regional centers offer significant pools of engineering design talent that is far less expensive than North American semiconductor designers. The growth of non-North American Design House firms therefore could portend some shifts in design employment away from the United States.

The most advanced Foundries are located primarily in the Asian countries of Taiwan and Singapore. If these countries remain the leading site for foundry services, continued growth of the Design House /Foundry model could result in substantial migration of semiconductor manufacturing employment from the United States to Southeast Asia. Nevertheless, a few Taiwanese firms have opened foundries in the United States. Moreover, Taiwan’s dominant position in the foundry industry faces significant competition from lower-cost production sites in other areas of Southeast Asia and elsewhere. Indeed, Malaysia and China are widely cited as important future sites for Foundries. Besides, global Foundry giant, Taiwan Semiconductor Manufacturing Company (tsmc), has faced the furious competition from other semiconductor giants, Samsung and Intel, to grasp the business recently.

Table 2.1: Design House by Location (2002).

Top Countries	Fabless Firms	Top Non-U.S. Cities	Fabless Firm
U.S.	475	Tel Aviv, Israel	14
Canada	30	Ottawa, Canada	13
Israel	29	Hsinchu, Taiwan	13
Taiwan	22	Seoul, South Korea	9
U.K.	22	Taipei, Taiwan	8
South Korea	13	Toronto, Canada	8
Germany	8	Cambridge, England	4
France	6		
Japan	5		
Sweden	5		
Switzerland	3		
India	3		
Spain	3		
Others	15		
Total 640	**640**		

Source: Arensman (2003).

The separation of design and manufacturing activities in the semiconductor industry thus appears to have produced geographic separation of design and production activities. Although there is some evidence of a similar geographic separation occurring in chemicals, the patterns in semiconductors are more dramatic and raise an important issue not treated in most analyses of vertical specialization – how do the "spillovers" and other links among the stages of an industry's value chain that are organizationally and potentially geographically separated influence future growth in vertical specialization within an industry? Obviously, the sustainability of both the "Design House" and "foundry" business models is based on the limited interdependence between these stages in the semiconductor industry's value chain in some product areas. But the dynamic effects of the shift of a growing share of the global semiconductor industry's production capacity to Southeast Asia are much more difficult to predict.

The long-term effects of expansion in the Design House /foundry model on the geographic location of manufacturing capacity and employment thus are uncertain, but on balance, growth in foundries is likely to result in the movement of production capacity and employment from the United States, Japan, and Europe to Taiwan, Singapore, Malaysia and mainland China. Even more uncertain are the effects of shifts in the regional distribution of production activity on the global distribution of semiconductor design and technology development activities. At present, the agglomeration economies that have supported the regional concentration of device design and R&D in a few areas around the globe remain strong, a situation that is similar to that of the chemical industry.

Nevertheless, the agglomeration effects that have sustained North American dominance of R&D employment in the semiconductor industry may weaken as the geographic dispersion of semiconductor design and manufacturing activities grows. There is little evidence from the history of the chemical industry that the entry of new producers in offshore locations shifted the geographic distribution of more knowledge-intensive activities, but the characteristics of the product-process technology linkage in semiconductors may be different. Very little research has attempted to compare such cross-industry differences in knowledge spillovers among stages of the value chain, despite the importance of these spillovers for long-term trends in vertical specialization and change in the location of high value added activities within these or other knowledge-intensive industries.

2.3 Shifting of Characters in the Semiconductor Industry

The technology shifting has been widely discussed since the last century. Ayres (1990) applied the theory of economic long cycles by the Russian economist, Kondratieff (1935) in order to explore the relationship among technological transformations, innovation, and economic growth. Nelson (1994) drew on an evolutionary theory of economic growth that links appreciative theorizing regarding growth and formal theorizing. He attempted to integrate the relatively coherent appreciative theoretical account of economic development with the development of the manufacturing sector. Lei (2000) examined the growing impact of technological convergence on the shifting of industry structure and the development of core competences, knowledge, and skill sets within firms. In addition to the technology shifting affecting economic development, von Zedtwitz and Gassmann (2002) discussed technology shifting or development through modeling R&D internationalization with the market view. Some researchers focused on industry shifting through the internationalization processes of firms. For example, Lau (2002) used theoretical perspectives to explain why firms with few product-oriented specific ownership advantages in an industrializing economy successfully engage in production-related foreign direct investment (FDI). Among examinations of the characters in industry development, Patibandla and Petersen (2002) attributed the shifting of the industry in human capital accumulation to the entry of multinational corporations (MNCs), which triggered a cumulative process of further human capital accumulation through externalities (spillovers) governed by firm-level and market structure dynamics. The supply chain of the industry’s development has also become prosperous and mature to some extent. Exploratory research was applied the supply chain as a mechanism for upgrading and transferring “appropriate practice” (Bessant, Kaplinsky & Lamming, 2003). Essletzbichiler and Rigby (2005) studied the technology shifting from the perspectives of competition, variety, and geography, remedying some empirical shortcomings by exploring the spatial shifting of variety in production techniques within three US manufacturing industries. They also suggested that technological variety exists and persists over time and that geography explains a significant portion of this variation.

The semiconductor industry has been one of the most important industries for the past three decades. Due to its critical position in modern industry, the research on the semiconductor industry is plentiful. From the viewpoint of knowledge flow and management in the semiconductor industry, Appleyard (1996) examined inter-firm information flows in the knowledge-intensive semiconductor industry. She applied survey data on inter-firm knowledge transfers in the semiconductor industry in order to explore why patterns of knowledge exchange are different both across industries and across countries. Chang and Tsai (2000) studied strategies adopted at different stages by Taiwan's semiconductor industry in its technological development, focusing specifically on the research consortium strategy and the case of the industry consortium. How the knowledge-based view can be applied to firm boundary decisions and the performance implications of those decisions has been examined (Macher, Mowery & Simcoe, 2002). At the center of this research was a theoretical and empirical examination of how firms most efficiently organized to solve different types of problems related to technological development, using the semiconductor industry as the empirical setting. Appleyard (1996) conducted her research regarding the semiconductor industry through the perspective of knowledge management due to the technology-intensive nature of the industry. There are many IT (Information Technology) studies of the semiconductor by specific countries or areas. The three-level model of internet commerce adoption (MICA) has been used in a survey of 287 companies and web sites in Taiwan (Peng, Trappey & Liu, 2005). They claimed that the IC manufacturing segment was conducting more financial transactions than the other segments, a result that matches earlier research showing that larger companies are most likely to implement e-business applications. Chen et al. (2008) applied the dynamic capabilities perspective in order to analyze the strategic information system alignment process in a real case of a semiconductor company in Taiwan. Hilmola (2007) explored the semiconductor industry as the fifth innovation cycle (Garvey, 1943) through stock market performance and manufacturing capability. Most of studies about the shifting or relationships of the characters are focused on economics (Berger and Lester, 2009), manufacturing capacity (Lee and Hsu, 2004) and strategy management (Guilhon, Attia & Rizoulieres, 2004). The semiconductor manufacturing industry was analyzed for different engineering collaboration mechanisms between Design House and Foundry during different stages of process technology (Guo, Su & Chang, 2004).

For the development trend, Ernst (2005) discussed the growing geographic mobility of chip design and its dispersion to Asia. He argued that, to cope with such demanding requirements, firms have a strong incentive to concentrate innovation in their home country. In addition to these issues, the influence of Internet-based “e-Business” applications on these trends was examined and their effects on the global production networks in the semiconductor industry were considered (Macher, Mowery & Simcoe, 2002). For the capacity planning aspect, many IDMs or design houses commonly suffer the capacity shortage issue of foundries when the industry is prosperous. A method that accepts this uncertainty of demand and used stochastic integer programming to find a tool set responsive to changes in demand has been presented by Hood, Bermon, & Barahona (2003). They considered a set of possible, discrete demand scenarios with associated probabilities, and determined the tools to purchase, under a budget constraint, to minimize the weighted average unmet demand. As to the decision quality of the supply chain, IC, Wu and Hsu (2009) clarified the terminology of decision quality in manufacturing strategy and defined the Critical Success Factor (CSF) as manufacturing practices in order to improve the decision quality of collaborative design in the IC supply chain. However, little research focuses on the insights of character shifting in semiconductor value chain technology during different wafer size eras and in different technology fields, especially when the character shifting of technology may overthrow the traditional understanding. As we know, the semiconductor industry is highly capital-intensive, so it would be natural to apply the strategic alliance approach to technology development. To provide semiconductor companies who want to select partners for R&D cooperation among different characters and technology fields with value-added directions and information is one of the most important reasons to discuss character shifting. It may also assist researchers who are interested in exploring the semiconductor technology shifting within characters. In addition to above researches, many patent related researches for the industry are explored.

2.4 Co-opetition Types

The value chain for the semiconductor industry is a typical The concept of co-opetition typically refers to the relationship between firms that simultaneously embraces both competition and cooperation (e.g., Brandenburger & Nalebuff, 1996). Thus, the concept of co-opetition comprises a complex combination of two opposite logics of interaction: the competitive paradigm, assuming that companies interact based on conflicting interests, and the collaborative paradigm, asserting that companies interact based on common interests in a certain area (Bengtsson & Kock, 2000; Cassiman et al., 2009; Dowling et al., 1996). Despite many risks and conflicts, cooperation with competitors is usually driven internally by the need to share R&D or production risks and costs, by the goal to pool resources, develop and expand markets together, address major technological challenges, and realize synergistic effects (Das & Teng, 2000; Huang et al., 2009; Tether, 2002), or externally by the requirement to comply with new regulations (Nakamura, 2003) or to develop common industry standards.

Here, we use co-opetition in the vein of Bengtsson & Kock (2000). According to these scholars, a firm is involved in co-opetition if it carries out cooperative activities with other actors the focal firm itself classifies as competing, regardless of whether or not the competition is in the same product area or in the same industry. Although co-opetitive activities can occur at multiple levels, such as at the firm level, the industry level, the level of strategic business units, the department level, or between teams (Gnyawali & Park, 2011; Luo et al., 2006; Tsai, 2002), we restrict our focus on co-opetitive innovation activities at the firm level.

Different theories have been used to assess the value of co-opetitive activities. Transaction cost theory focuses on the competitive dimension and therefore on the pitfalls of this strategy. Reasoning based on a transaction cost rationale renders co-opetition as a risky strategy because of the knowledge paradox1 (Madhok, 1997; Nickerson & Zenger, 2004) on the one hand and the involuntary leakage of tacit knowledge to the collaborating, yet competing partners, on the other hand (Cassiman & Veugelers, 2002). Incentives for opportunistic behavior originating from the competitive dimension of this strategy theoretically undermine the benefits of the cooperative dimension (Quintana-García & Benavides-Velasco, 2004).

Arguments originating from the resource-based view (Barney, 2001, 1991; Teece et al., 1997) focus more on the cooperative dimension and thus, the benefits of co-opetitive behavior. Firms gain a competitive advantage by absorption, assimilation and transformation of knowledge from different areas (Kessler et al., 2000; Kogut & Zander, 1996). The results of these activities accumulate as knowledge assets specific to the individual firm (DeSarbo et al., 2007; Wang et al., 2009). Competitors are valuable sources of complementary knowledge and resources, which can be accessed through cooperation (Grant & Baden-Fuller, 1995). The resource-based view hence renders coopetitive activities as an important way to increase the innovation capabilities of firms. In a first step, co-opetition can be interpreted as a collective effort in the form of cooperation leading to value creation, i.e., by creating new or improving current products or services as well as by establishing new or enlarging current markets. In contrast to the first step, the second rather focuses on individual firm aspects as it comprises a company's competitive effort to appropriate value. How firms protect their intellectual assets and how they appropriate their returns, hence is largely contingent on firm specific cooperative and competitive strategies (Ritala & Hurmelinna-Laukkanen, 2009). In sum, different theories can explain advantages and disadvantages of a co-opetition strategy.

Even though co-opetition is challenging for the involved firms, it creates certain advantages such as a positive effect on new product development and innovation as it enhances the involved firms' capacity to innovate (Gnyawali & Park, 2011; Ritala & Hurmelinna-Laukkanen, 2009). These effects exceed those generated by competitive relationships because partnering companies can control their competitors more effectively (Chen & Chen, 2011; Quintana-García & Benavides-Velasco, 2004). Despite the positive effects of co-opetition on value creation, companies use this strategy as a means to imitate rather than to generate radical innovations due to opportunistic behavior and knowledge spillover (Mention, 2011; Monjon & Waelbroeck, 2003).

When co-opetition is undertaken, it shows different structures according to the level of commitment lavished by competitors on both cooperative technology developments and collaborative market actions. Specifically, the article analyses cases of co-opetition concerning: a) exchanges of patents and knowledge; b) collaborative research & development activities; c) market alliances for setting new standards, and (d) collaborative agreements to integrate existing businesses. Each type of co-opetition can depict either a specific choice of a firm to effectively compete in the marketplace or a portfolio of firm's co-opetitive activities that evolves over time.

The structure of the global semiconductor industry has shifted from one dominated by vertical integration to a more complex structure that blends vertical specialization and vertical integration. Specialized design and manufacturing firms have entered the industry in large numbers, and the growth of "foundry" firms has been associated with a substantial shift in production capacity investment to Southeast Asia. In semiconductors, like chemicals, vertical specialization has facilitated the entry of new firms, many of which are located outside of the regions that were homes to established firms. But like chemicals, the greatest effect of vertical specialization thus far appears to be in shifting the location of production, rather than product design and R&D, activities. In many respects, the history of vertical specialization in the semiconductor industry is a textbook illustration of the effects of growth in the "extent of the market" on the entry of specialist firms. Nonetheless, thus far there are limits to the operation of the vertically specialized structure within semiconductors, as "bleeding-edge" products still require the integration of product design and process technology development.

An interesting contrast between vertical specialization in semiconductors and chemicals concerns the role of technology licensing in the development of this industry structure. As we noted earlier, both of these industries are relatively "mature," in that both industries have been in existence for decades, their markets are global, and entry has slowed somewhat. In chemicals, vertical specialization both caused and was accelerated by the technology licensing efforts of the SEFs and the major integrated firms. In semiconductors, however, arms-length technology licensing has been less common, and considerable inter-firm technology transfer has taken place. But the primary sources of process technology transfers in semiconductors have been by established integrated producers, rather than by specialist firms. In contrast, the recent growth in markets for "design cores" and product-related IP has been spurred by growth in the number of Design House specialists, although the inter-firm technology transfers that characterize these transactions deal in component technologies, rather than "turnkey" design packages.

In semiconductors, some product markets (in particular, microprocessors and DRAMs) still require close coordination between product design and process development, and vertical integration remains essential to competitive strength. These products resemble specialty chemical products in their demands for vertical integration. Many integrated device manufacturers have adapted to this competitive entity by outsourcing a portion of their manufacturing needs to foundries for (typically) older products and process technologies, freeing up capital and technical talent to focus on the development and manufacture of more advanced products. A number of Design House and foundries compete head-on in well-established product markets where CMOS is the manufacturing industry standard, while several IDMs remain vertically integrated in areas where internal communication is critical over the product design and manufacturing interface.

The strategies of established firms affected the development of vertical specialization in each of these three industries through their management of inter-firm technology flows. As we noted in our discussion of the chemical industry, the growth of SEF-mediated international technology licensing led a number of integrated firms to expand their licensing activities as well, accelerating the international diffusion of process technologies for commodity chemicals. The situation in semiconductors has some similarities with that in chemicals, in that the growth of vertically specialized manufacturing firms has been aided by product and technology licensing agreements and alliances involving Foundries and integrated producers. In both of these industries, the growth of international markets for technology licensing and other vehicles for the exploitation of their knowledge-based assets led established, vertically integrated firms to catch strategies that accelerated entry and vertical specialization. In addition to the vertical integration and specialization for the semiconductor industry, the co-opetitoin phenomenon has spread in the semiconductor industry. In short, IDMs are customers for Foundries when their manufacturing capacity is shortage traditionally. More and more IDMs, AMD, Intel, and Samsung, diversified their business models from vertical integration character to Foundry.

Chapter 3

Research Methods

In this chapter, we describe research methodologies for positioning and shifting of character and technology focuses in the semiconductor major value chain.

3.1 Methodologies

For the character shifting, we used patent count and average patent citation count to stand for the activity and quality, respectively. We also examined the technology shifting by characters and wafer size eras through the patent analysis techniques above. As to the specific companies of IDM wise on technology focus, we built the indices to measure the productivity and the quality of technology focus. The productivity of technology focus means the performance of resources invested in specific technologies for each company or industry. The quality of technology focus means the recognition of the performance of resources invested in specific technologies for each company or industry. We designed combination charts with productivity (PT_d) and quality (QT_d) of technology focuses on wafer-design application patents as the X-axis and Y-axis to simultaneously express the productivity and quality of technology focus for the selected IDM companies,. Similarly, we designed combination charts with productivity (PT_p) and quality (QT_p) of technology focuses on wafer-process patents as the X-axis and Y-axis.

3.1.1 Shifting of Characters

The character shifting of technology in the semiconductor value chain is the main focus of this study; therefore, we analyzed the primary patent data within technical characters to understand their shifting. That is, the patent count, average patent citation count, and the combination of the average patent citation count with relative patent count share will be displayed by wafer size eras and characters. We also applied the ANOVA (analysis of variance) procedure to verify whether the difference between average patent citation counts is significant in different wafer size eras and characters. In order to understand the difference resulting from each wafer size era by character, we also used the Post Hoc Test (Scheffe) to further clarify the relationships among them.

3.1.2 Shifting of Wafer Design Application Patents and Wafer Process Patents

To analyze the technology fields of each character in detail, we used the patents of each technology field to identify which technology field is most competitive within characters and wafer size eras. We targeted the patents from seven major technology fields, accounting for 75% of the total patent count. These are classified as wafer design application patents or wafer process patents. Electronics Communication, Computer Software and Hardware, and Digital Information Storage belong to wafer design patents; Semiconductor Making or Forming, Semiconductor Manufacturing, Active Solid-State Devices, and Chemistry belong to wafer process patents.

3.1.3 Analysis of Characters by Wafer Design Application Patents and Wafer Process Patents

To obtain valuable insights into the shifting in the semiconductor industry, we combined the shifting of characters with classified patents. Thereby, it is expected to obtain a picture of the overall shifting of each character from the based upon classified patents. The combination of patent quality and the relative patent activity share is composed of the average patent citation count and relative patent count share. The relative patent count share is the patent count of the targeted character or technology field divided by patent count of all characters or technology fields. We designated relative patent count share as the X-axis and average patent citation count as the Y-axis to measure relative patent activity share and patent quality, respectively, as shown in Fig. 4.4. There are four quadrants in the chart divided by the average of relative patent count share and average patent citation count by wafer size eras. The upper right quadrant represents the star level, with high patent share and high patent quality; the upper left quadrant represents the potential level, with high patent quality but low patent share; the lower right quadrant represents the saturated level, with high patent share but low patent quality; and the lower left quadrant represents the poor patent level, with low patent share and low patent quality. The most positive development trend is moving to the upper right quadrant, with high patent quality and patent activity share.

3.2 Data Collections and Procedures

The semiconductor industry's productivity has been historically driven by Moore's law, which predicts that the numbers of transistors on a chip will double every 18 to 24 months. By following Moore's law and reducing the transistor cost or cost per function by 30% each year, the industry has achieved unparalleled growth by providing more capability at equal or lower cost. Wafer size changes have been regular productivity enhancements over the years. The productivity benefit is trivial: when the wafer area more than doubles, but the cost of the new tool set for the same number of wafer starts increases by only 30-40% (which is typical), the cost per area decreases by 30-50% — an annualized improvement of about ~4% when wafer size changes occur about ever 10 years. This means that every wafer generation brings an intrinsic productivity boost. It is critical to construct the analyzed time frame of the study; authors divided the target period (1979-2009) into three major wafer size eras, 1979-1991, 1989-1999, and 1997-2009 for the 6- and pre 6-inch, 8-inch, and 12-inch wafer eras, respectively, which are the classification referred to by Chien et al. (2007). There is time overlap for each wafer size era because it is not easy to identify a clear-cut division between eras. The categorization of each company is followed by the professional industry research institutes like IC Insights, and Gartner. That is, if a company classified as IDM by the professional industry institute, analysts defined it as IDM even if it is a part-time Foundry company.

3.2.1 Data Collections

For character shifting part, the research team designed a query program to collect the patent count and patent cited/citing counts of the semiconductor industry from the USPTO for 30 years (1979 - 2009) by the three major semiconductor industry technology eras. Because the semiconductor industry is a cross-field industry, the authors searched the related patents of other technology fields to query the patent data as completely as possible. To focus on the business view of major characters, the authors eliminated non-profit organizations like universities and research centers as well as related front-end and back-end suppliers like tool vendors and testing/assembly houses. In addition, the authors selected dominant companies which accounted for 80% of the total patent count and patent citation counts, as there is a high concentration ratio of patent count in the semiconductor industry. The framework of the study is an analysis of two elements. One element is explored by technical characters; the other is analyzed by the classified patents of wafer design application patents and wafer process patents. The authors analyzed the patent information from the USPTO, including patent count, average patent citation count, and the combination of the average patent citation count and relative patent count share, to measure patent activity, patent quality, and integrated patent performance respectively.

For positioning and shifting of technology focus on specific IDM companies, we classified the patents involving the semiconductor field according to how they were sorted by the National Bureau of Economic Research (NBER) [26]. NBER identifies 12 technology fields in the semiconductor industry. The NBER has specific definitions for category, subcategory, and US patent classes, as shown in Table 3.1. We selected eight major technology fields (subcategories), which accounted for nearly 80% of the total number of semiconductor patents, including electronics communication, computer software and hardware, digital information storage, semiconductor making or forming, semiconductor manufacturing, semiconductor package, active solid-state devices, and chemistry, as shown in Table 3.1. A total of 75 US patent classes are distributed among these eight major technology fields. For example, electronics communication is composed of US patent classes 178 (Telegraphy) and 333 (Wave transmission lines and networks), as shown in Table 3.2. All 75 patent classes are used in this paper. To focus on the business view of the assignees of patents, we excluded non-profit organizations such as universities and research centers, as well as related front-end and back-end suppliers such as tool vendors and testing or assembly houses. In short, we only focused on corporate assignees. Then, we targeted the patents in the semiconductor industry, including IDMs and Foundries, from the major technology fields; these accounted for a total of 109,773 patent counts granted by the USPTO, as shown in Table 3.2. Since most Design Houses (such as Qualcomm, Broadcom, and Nvidia) possessed patents mainly for electronics communication, computer software and hardware, and digital information storage, we classified these patents of technology fields as “wafer-design application patents.” Because most Foundry companies possessed patents mainly for semiconductor making or forming, semiconductor manufacturing, semiconductor packaging, active solid-state devices, and chemistry, we classified these patents as “wafer-process patents” to reflect their industry properties, as is shown in Table 3.1. To provide a base for comparison, we also explored the technology focus positions for overall Foundry companies and the shifting of that focus as it averagely aligned with relative research methods.

There are several basic patent data applied in this research to detect the positions of targeted IDM companies. All patent data were retrieved from USPTO records created from 1981 to 2010. The total number of patents in wafer-design application and wafer-process portray the amount of technology production. The numbers of wafer-design application patents and wafer-process patents were evaluated for the different technology fields of each selected IDM company. Their shares were used to measure the preferences or specialties for the selected IDM companies and the overall IDM and Foundry industries. Their total citation counts were used to measure the overall citation impact of relative patents. Their average patent citations were defined as the ratio of total citation count and total patent counts on wafer-design application technology and wafer-process technology, respectively.

Table 3.1: Major technology fields for the semiconductor industry

Classifications	**Major Technology Fields** **(Subcategory Name)**	**US Patent Classes** **(Main)**
Wafer-design application	Electronics communication	Total 12 patent classes: 178 (Telegraphy), 333 (Wave transmission lines and networks), 340, etc.
	Computer software and hardware	Total 17 patent classes: 341 (Coded data generation or conversion), 380, 382, etc.
	Semiconductor devices- Digital information storage	Total 4 patent classes: 360 (Dynamic magnetic information storage or retrieval), 365, etc.
Wafer-process	Semiconductor making or forming	Total 1 patent class: 505 (Superconductor technology: apparatus, material, process)
	Semiconductor devices- Semiconductor manufacturing	Total 1 patent class: 438 (Semiconductor device manufacturing: process)
	Semiconductor package	Total 1 patent class: 53 (Package making)
	Semiconductor devices- Active solid-state devices	Total 1 patent class: 257 (Active solid-state devices, e.g., transistors, solid-state diodes)
	Chemistry	Total 38 patent class: 23 (Chemistry: physical processes), 34, etc.

3.2.2 Procedures

Because the semiconductor industry is a cross-field industry, we searched the related patents of other technology fields and further queried the patent data. To focus on the business view of major players, we excluded non-profit organizations such as universities and research centers, as well as related front-end and back-end suppliers such as tool vendors and testing/assembly houses. Meanwhile, we also defined the character of the semiconductor industry for each company, IDM, or Foundry by professional industrial institutes, such as IC Insights and Gartner, because business diversification has become increasingly popular in the industry. In short, if a company was classified as an IDM by a professional industrial institute, we defined it as an IDM, even if it is also a part-time foundry company. We queried the overall IDM companies to explore their technology focuses over the past 3 decades (1981-2010) from the United States Patent and Trademark Office (USPTO) database. Since there is a high concentration ratio of patent count in the semiconductor industry, selected the major IDM companies that accounted for 66% of the total patent count; 33 other IDM companies accounted for the remaining 34% in the total USPTO patent count, as shown in Table 3.2. Since other 34% of the total patent count was distributed across another 33 IDM companies, the research team selected the main 11 companies as the focus in this study.

Table 3.2: Selected IDM companies (1981-2010)

Company	Abbreviation	Number of Total Patents (P)	Share(%)
International Business Machines Corporation	IBM	15410	15%
Hitachi, Ltd.	HITACHI	6819	7%
Micron Technology, Inc.	Micron	6550	6%
Toshiba Corporation	Toshiba	5844	6%
NEC Electronics Corporation	NEC	5818	6%
Samsug Electronics Co., Ltd.	Samsung	5604	5%
Intel Corporation	Intel	5244	5%
Fujistsu Limited	FUJITSU	5106	5%
Mitsubishi Corporation	MITSUBISHI	4571	4%
Advanced Micro Devices, Inc.	AMD	4031	4%
Texas Instruments Inc.	TI	3761	4%
Selected 11 IDM Companies		**68758**	**66%**
Other IDM Companies (33 companies)		**35919**	**34%**
Total IDM Companies		**104677**	**100%**
Foundry Industry		**5096**	
Total- IDM & Foundry		**109773**	

Note: Sorted by Share of Selected 11 IDM Companies

3.3 Indicators

3.3.1 Indicators for Character Shifting

The character shifting of technology in the semiconductor value chain is the main focus of this study; therefore, we analyzed the primary patent data within technical characters to understand their shifting. Various patent indicators such as average patent cited times, and the combination of the average patent cited times and relative patent count share were used to measure the patent activity, patent quality, and the combination of the patent quality and relative patent activity share, respectively. That is, the patent count, average patent citation count, and the combination of the average patent citation count with relative patent count share will be displayed by wafer size eras and characters. We also applied the ANOVA (analysis of variance) procedure to verify whether the difference between average patent citation counts is significant in different wafer size eras and characters. In order to understand the difference resulting from each wafer size era by character, we also used the Post Hoc Test (Scheffe) to further clarify the relationships among them.

3.3.2 Indicators for Position and Shifting of IDMs

It was our aim to explore positioning and shifting for the selected IDM companies from the perspective of technology focus. The productivity of technology focus means the performance of resources invested in specific technologies for each company or industry. The quality of technology focus means the recognition of the performance of resources invested in specific technologies for each company or industry. We designed combination charts with productivity (PT_d) and quality (QT_d) of technology focuses on wafer-design application patents as the X-axis and Y-axis to simultaneously express the productivity and quality of technology focus for the selected IDM companies,. Similarly, we designed combination charts with productivity (PT_p) and quality (QT_p) of technology focuses on wafer-process patents as the X-axis and Y-axis. The two indices used to explore the position of each IDM company's technology focus are:

(1) Productivity:

The productivity of technology focuses on wafer-design application for company i (PT_d)

$$PT_{d(i)} = \frac{S_{d(i)} - S_{d(Min)}}{S_{d(Max)} - S_{d(Min)}} \tag{1}$$

where $S_{d(i)}$ denotes the share of wafer-design application patents for company i and $S_{d(Min)}$ and $S_{d(Max)}$ denote the minimum and maximum shares, respectively, of wafer-design application patents among selected companies.

The productivity of technology focuses on wafer-process for company i (PT_p)

$$PT_{p(i)} = \frac{S_{p(i)} - S_{p(Min)}}{S_{p(Max)} - S_{p(Min)}} \tag{2}$$

where $S_{p(i)}$ denotes the share of wafer-process patents for company i and $S_{p(Min)}$ and $S_{p(Max)}$ denote the minimum and maximum shares, respectively, of wafer-process patents among selected companies.

(2) Quality:

The quality of technology focuses on wafer-design application for company i (QT_d)

$$QT_{d(i)} = \frac{AC_{d(i)} - AC_{d(Min)}}{AC_{d(Max)} - AC_{d(Min)}} \tag{3}$$

where $AC_{d(i)}$ denotes the average patent citation of wafer-design application patents for company i and $AC_{d(Min)}$ and $AC_{d(Max)}$ denote the minimum and maximum average patent citations of wafer-design application patents among selected companies, respectively.

The quality of technology focuses on wafer-process for company i (QT_p)

$$QT_{p(i)} = \frac{AC_{p(i)} - AC_{p(Min)}}{AC_{p(Max)} - AC_{p(Min)}} \quad (4)$$

where $AC_{p(i)}$ denotes the average patent citation of wafer-process patents for company i and $AC_{p(Min)}$ and $AC_{p(Max)}$ denote the minimum and maximum average patent citations of wafer-process patents among selected companies, respectively.

3.3.3 Integrated Measurement for Wafer-design Application and Wafer-process Technologies

We designed an integrated index, the length from the origin (a reference point corresponding to the two index scores) of wafer-design application patents (L_d) and wafer-process patents (L_p) to obtain an integrated measurement of wafer-design application technologies, the productivity and quality of technology focuses on wafer-design application (PT_d / QT_d) and wafer-process (PT_p / QT_p) for the selected IDM companies. The value of L_d or L_p will be between 0 (both PT_d and QT_d or PT_p and QT_p are equal to 0) and 1.4 (both PT_d and QT_d or PT_p and QT_p are equal to 1).

In summary, the equations are:

Integrated measurement of wafer-design application technologies (L_d)

$$L_{d(i)} = \left[PT_{d(i)}^{\;2} + QT_{d(i)}^{\;2}\right]^{1/2} \quad (5)$$

where $PT_{d(i)}$ and $QT_{d(i)}$ denote the productivity and quality of technology focuses on wafer-design application for company i, respectively.

Integrated measurement of wafer-process technologies (L_p)

$$L_{p(i)} = \left[PT_{p(i)}{}^2 + QT_{p(i)}{}^2 \right]^{1/2} \tag{6}$$

where $PT_{p(i)}$ and $QT_{p(i)}$ denote the productivity and quality of technology focuses on wafer-process for company i, respectively.

Chapter 4

Shifting of Characters in the Semiconductor Industry

In this chapter, we provide the research results for the positioning and shifting of characters in the semiconductor industry. It is obvious that the semiconductor industry is a prosperous industry by patent perspectives.

4.1 Development Trend Shifting of Characters

4.1.1 Patent Count and Average Patent Citation Count

From the study's result, it is clear that the semiconductor industry has been a prosperous industry for past 30 years (1979-2009) as measured by patent count or average patent citation count by wafer size eras, as shown in Fig. 4.1. If its development is traced by the characters of the semiconductor industry, IDM achieved the leading position on patent count, as shown in Fig. 4.2. Nevertheless, in the average patent citation count by character, IDM (2.42) received the lowest ranking among the three characters in the 12-inch wafer size era. This shows that the overall performance for IDM in patent analysis is not as strong as expected, especially in patent quality. Design House reached its peak in the average patent citation count in the 8-inch wafer size era, as shown in Fig. 4.2.

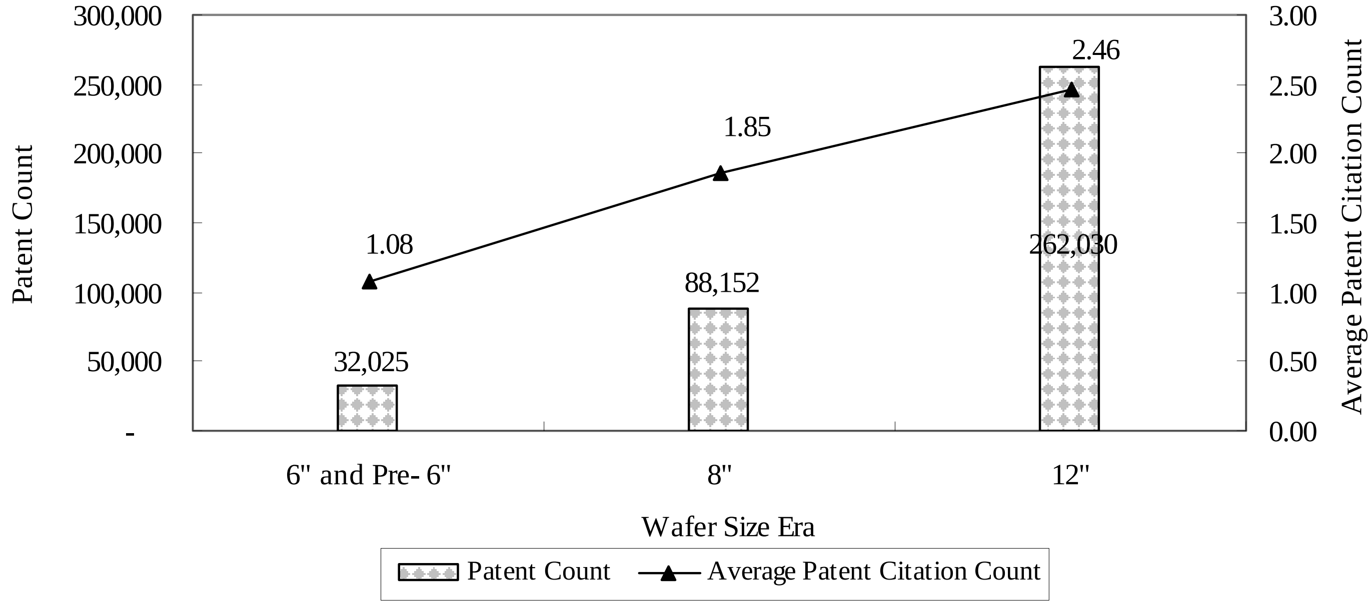


Fig.4.1: Patent count and average patent citation count by wafer size eras

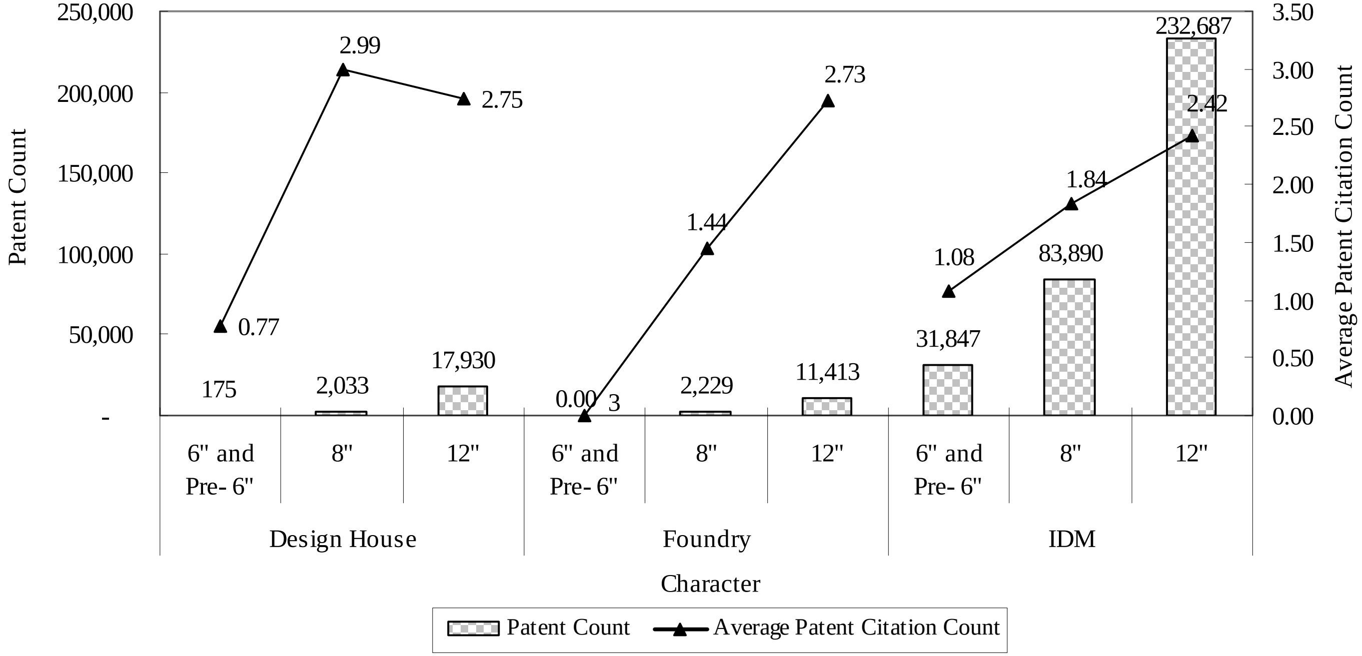


Fig.4.2: Shifting of patent count and average patent citation count by characters

Based upon the ANOVA test result, the "average patent citation count" of each character by wafer size era is significantly different, as shown in Table 4.1. The difference in the average patent citation count of each character by wafer size era is also significant in Table 4.2. That is, the "average patent citation count" for wafer size era or for each character--Design House, Foundry, and IDM--is statistically different.

Table 4.1: ANOVA of average patent citation count by wafer size eras

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F
Between Groups	67853	2	33926.6	1572.27
Within Groups	8247218	382204	21.6	
Total	8315071	382206		

Table 4.2: ANOVA of average patent citation count by characters

Character	Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F
Design House	Between Groups	649	2	324.3	6.18
	Within Groups	1053854	20096	52.4	
	Total	1054502	20098		
Foundry	Between Groups	3103	1	3103.3	119.65
	Within Groups	353788	13640	25.9	
	Total	356891	13641		
IDM	Between Groups	61108	2	30554.2	1562.34
	Within Groups	6814810	348463	19.6	
	Total	6875919	348465		

The Post Hoc Test (Scheffe) does not apply to the Foundry character since it has only two wafer size eras, and it can be verified by the ANOVA as shown in Table 4.2. In the average patent citation count by characters, the difference is significant for each character among wafer size eras, except in Design House's shifting from the 8-inch wafer size era to the 12-inch. That is, the growth of Foundry and IDM in the “average patent citation count” is significant measured by either wafer size eras or characters. For Design House, it is only significant in the shifting from the 6- and pre 6-inch wafer size era to the 8-inch.

4.1.2 Position by Characters

IDM is moving to the upper left quadrant (high average patent citation count but low relative patent count share) gradually, although it still dominates the relative patent count share consistently as shown in Fig.4.3. It is noteworthy that IDM’s “average patent citation count” measurement was below average for the 8-inch and 12-inch wafer size eras. This implies that patent quality development for the IDM character is declining compared with the Design House and Foundry characters. Design House reached a peak in the 8-inch wafer size era; since then, it has been moving toward the lower right quadrant (high relative patent activity share but low patent quality). The Foundry character was a potential star among the three characters, as shown in Fig.4.3. It is the only character moving in the most positive development direction, toward the upper right quadrant (high patent share and high patent quality).

The Foundry character is like a teenager with high potential for both patent count share and average patent citation count. Conversely, the IDM character is in the middle phase of its existence and is trending downward in its relative patent activity share or patent quality, especially in the 12-inch wafer size era. Last but not least, the Design House character has not shown a clear trend in the development of patents, but it is flat in patent quality in the 12-inch wafer size era. In short, the combination of the average patent citation count with relative patent count share reveals extreme patterns for IDM and Foundry/Design House. Since IDM dominated significantly in relative patent activity share, it remains in the top position. We discuss the insights derived from the data in great details by the following sections.

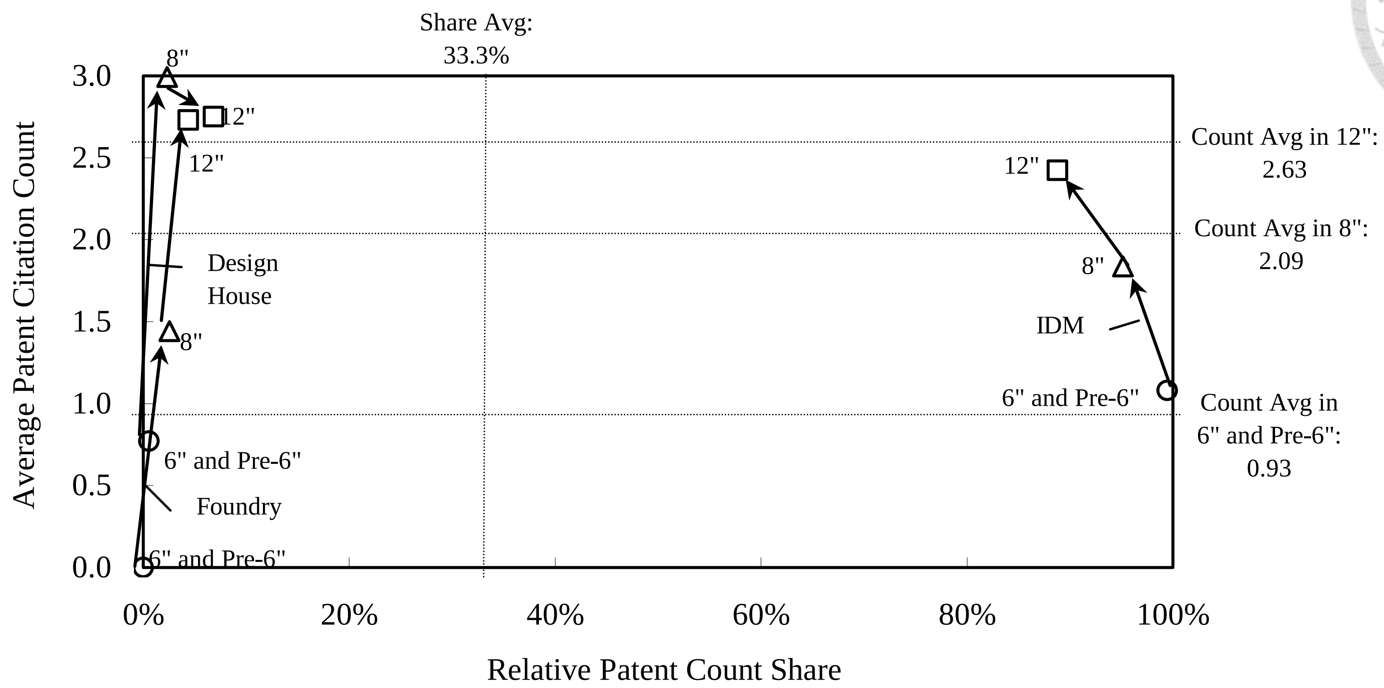


Fig.4.3: Relative patent count share vs. average patent citation count by wafer size eras and characters

4.2 Shifting of Wafer-design Application Patents and Wafer-process Patents

Computer Software and Hardware (108,225), Electronics Communication (71,658), and Digital Information Storage (63,664) are the top three technology fields in patent count for past 30 years, as shown in Table 3.3. It is interesting that all these leading technology fields are classified as Wafer Design Application Patents, implying that Wafer Design Application Patents constituted the major share among all targeted patents. In average patent citation count, Digital Information Storage (3.22), Semiconductor Making or Forming (2.72), and Semiconductor Manufacturing (2.40) are the top three technology fields, as shown in Table 4.3. Except for Digital Information Storage classified as wafer design application patents, both Semiconductor Making or Forming and Semiconductor Manufacturing are classified as wafer process patents. This implies that these technology fields are competitive on their average patent citation count. Only the Digital Information Storage technology field is performing well on both patent count and average patent citation count, and wafer application design patent measures are lower for average patent citation count than for patent count.

In the ANOVA test result, the “average patent citation count” of the semiconductor industry varies significantly. The data also have been tested by the Post Hoc Test (Scheffe) with a result of significant difference between each other except for Computer Software/Hardware and Semiconductor Manufacturing.

Table 4.3: Summary of patent count and average patent citation count by technology fields and characters

Index	Character	Wafer Design Application Patent			Wafer Process Patent				Total
		Electronics Communication	Computer Software and Hardware	Digital Information Storage	Semiconductor Making or Forming	Semiconductor Manufacturing	Active Solid-State Devices	Chemistry	
Patent Count	Design House	5,387	6,113	3,320	717	2,415	1,384	515	19,851
	Foundry	71	682	956	4,840	3,378	2,306	1,091	13,324
	IDM	66,200	101,430	59,388	22,367	21,764	37,761	29,929	338,839
	Semiconductor Industry	71,658	108,225	63,664	27,924	27,557	41,451	31,535	372,014
Patent Cited Times	Design House	11,522	12,143	16,326	1,244	10,524	3,248	360	55,367
	Foundry	46	1,144	3,507	16,035	8,584	4,024	836	34,176
	IDM	99,806	241,850	185,389	58,560	47,128	81,070	31,338	745,141
	Total	111,374	255,137	205,222	75,839	66,236	88,342	32,534	834,684
Average Patent Cited Times	Design House	2.14	1.99	4.92	1.74	4.36	2.35	0.70	2.79
	Foundry	0.65	1.68	3.67	3.31	2.54	1.75	0.77	2.56
	IDM	1.51	2.38	3.12	2.62	2.17	2.15	1.05	2.20
	Semiconductor Industry	1.55 **	2.36	3.22 **	2.72 **	2.40	2.13 **	1.03 **	2.24

Note:
** significant at 1% level

4.2.1 Shifting of Major Technology Fields

We continued to examine the shifting trend of patent codes by wafer size eras. It could be found that four out of seven technology fields are moving toward the upper right quadrant (high patent quality and high relative patent activity share). They include one technology field in the character of wafer design application (D) patents, Computer Software and Hardware, and three technology fields in the character of wafer process (P) patents: Active Solid-State Devices, Semiconductor Making or Forming, and Semiconductor Manufacturing. However, there are two technology fields, Chemistry and Electronics Communication, moving to the upper left quadrant (high average patent citation count but low relative patent count share). This implies that most technology fields are on a positive trend, improving in both patent quality and relative patent activity share, as shown in Fig. 4.4. From the shifting trend, three out of four technology fields are moving to the star level in wafer process patents, while only one out of three technology fields is moving to the star level in wafer design application patents. That is, technology fields in wafer process patents generally perform better than those in wafer design application patents on the shifting trend.

In the 12-inch wafer size era, Computer Software and Hardware and Digital Information Storage in wafer design application patents are at the star level; Semiconductor Making or Forming and Semiconductor Manufacturing and Active Solid-State Devices in wafer process patents are at the potential level; Electronics Communication in wafer design application patents is at the saturated level; Chemistry in wafer process patents is at the poor level.

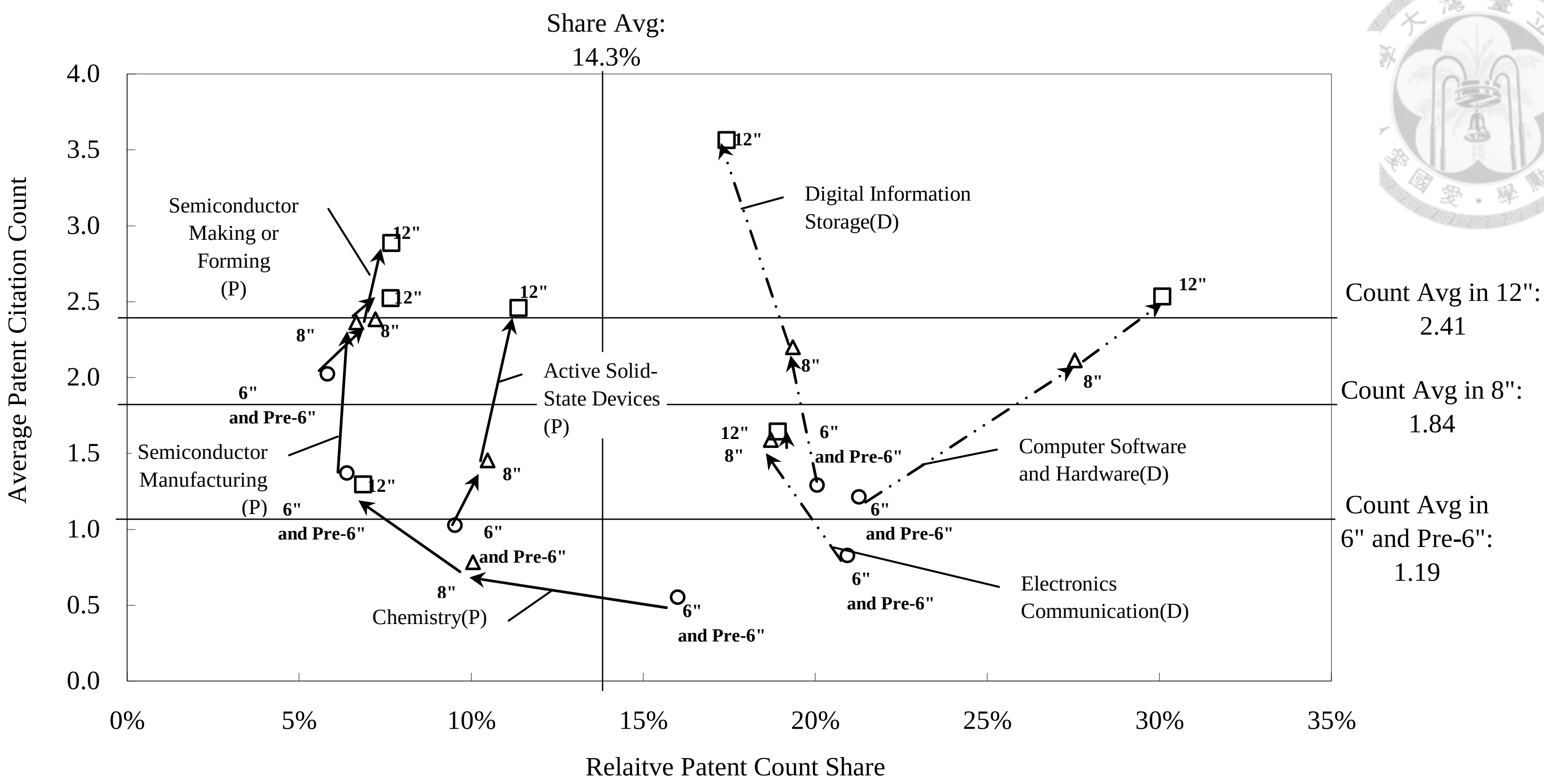


Fig. 4.4: Relative patent count share vs. average patent citation count by wafer size eras and technology fields

4.2.2 Push Patents or Pull Patents

Traditionally, the wafer design application (D) patents are regarded as the pull patents, which have a relatively leading position in the combination of patent quality and relative patent activity share, as shown in Fig. 4.4. Inversely, the wafer process (P) patents are regarded as the push patents. Thus, wafer process patents are the followers in the semiconductor industry. However, the shifting trend has changed in the latest 12-inch wafer size era, as shown in Fig. 4.4. Three out of four technology fields in wafer process patents are moving toward the upper right area (high average patent citation count and high relative patent count share), whereas only one out of three technology fields in wafer design application patents is moving toward the upper right area. It is believed that in the near future, wafer process patents will become the pull patents.

4.3 Shifting of Characters & Classified Patents

4.3.1 Design House

The analysis of the shifting for each technology field shows that Design House hit its record in the 8-inch wafer size era. That is, it is moving toward the negative area in the 12-inch wafer size era. In the latest 12-inch wafer size era, Digital Information Storage in wafer design application patents (D) is the only technology field at the star level; Semiconductor Making or Forming and Chemistry in wafer process (P) patents, along with Active Solid-State Devices in wafer design (D) patents, are the relatively poorer technology fields, as shown in Fig. 4.5.

The technology shifting of the Design House character seems troubling. Although Design House is supposed to have good performance in wafer design application patents, it had only one outstanding technology field, Digital Information Storage.

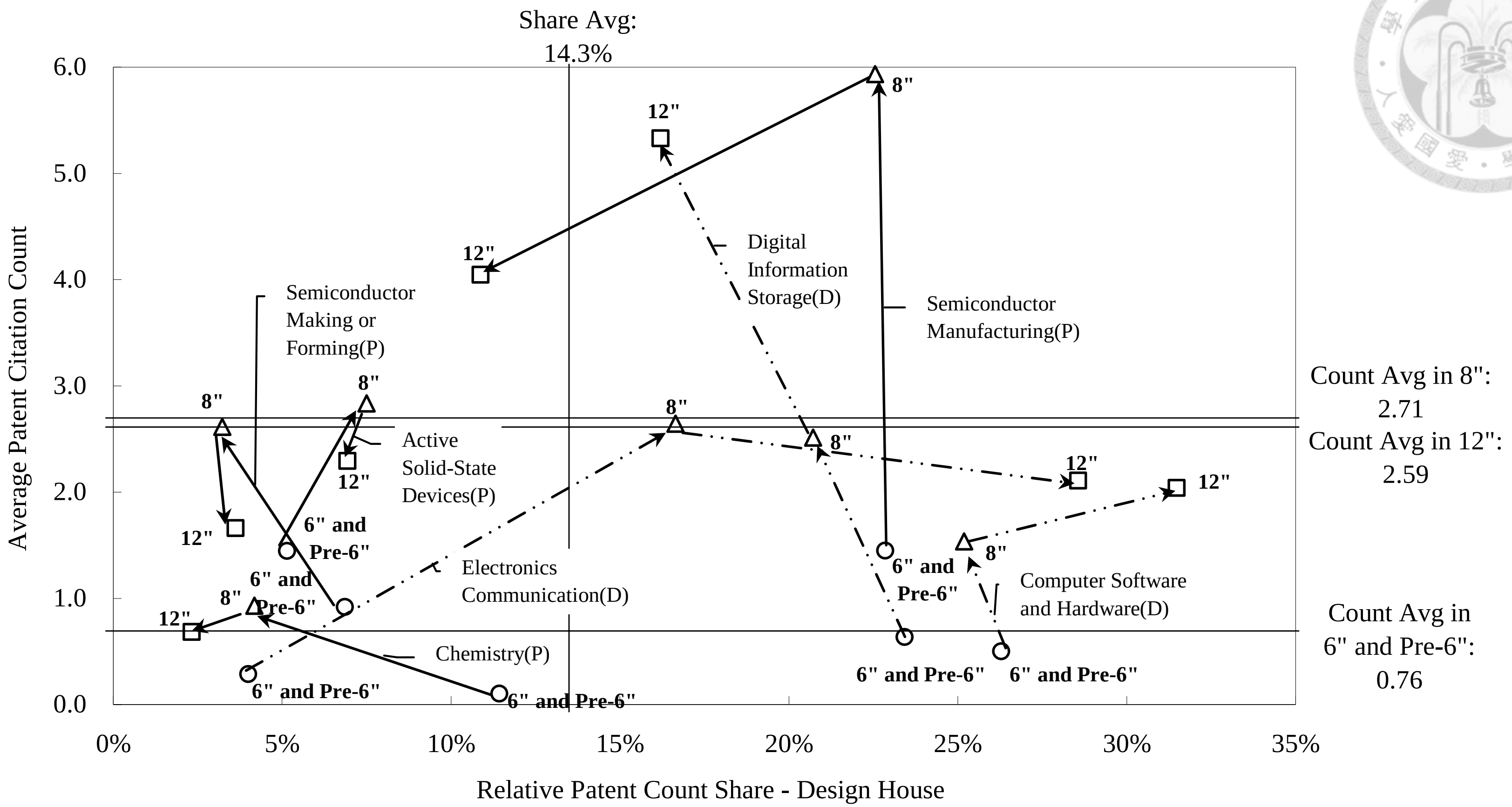


Fig. 4.5: Relative patent count share vs. average patent citation count by wafer size eras and technology fields (Design House)

4.3.2 Foundry

Most of the technology fields of Foundry are moving toward the upper right quadrant, demonstrating that this character is on the road to good patent share and patent quality. In the latest 12-inch wafer size era, Semiconductor Making or Forming and Semiconductor Manufacturing in wafer process patents (P) are the two relatively outstanding technology fields, and Digital Information Storage in wafer design application patents (D) is making marked progress in patent quality, as shown in Fig. 4.6. The outcome shows that Foundry not only performs well in wafer process patents but also in wafer design application patents. This implies that the power of the Foundry character is growing and even threatens the other two characters, IDM and Design House. One of the major reasons is the fact that IDM and Design House cooperated closely with Foundry to reduce their R&D expenditure, which has improved the technology level of Foundry for the past two decades.

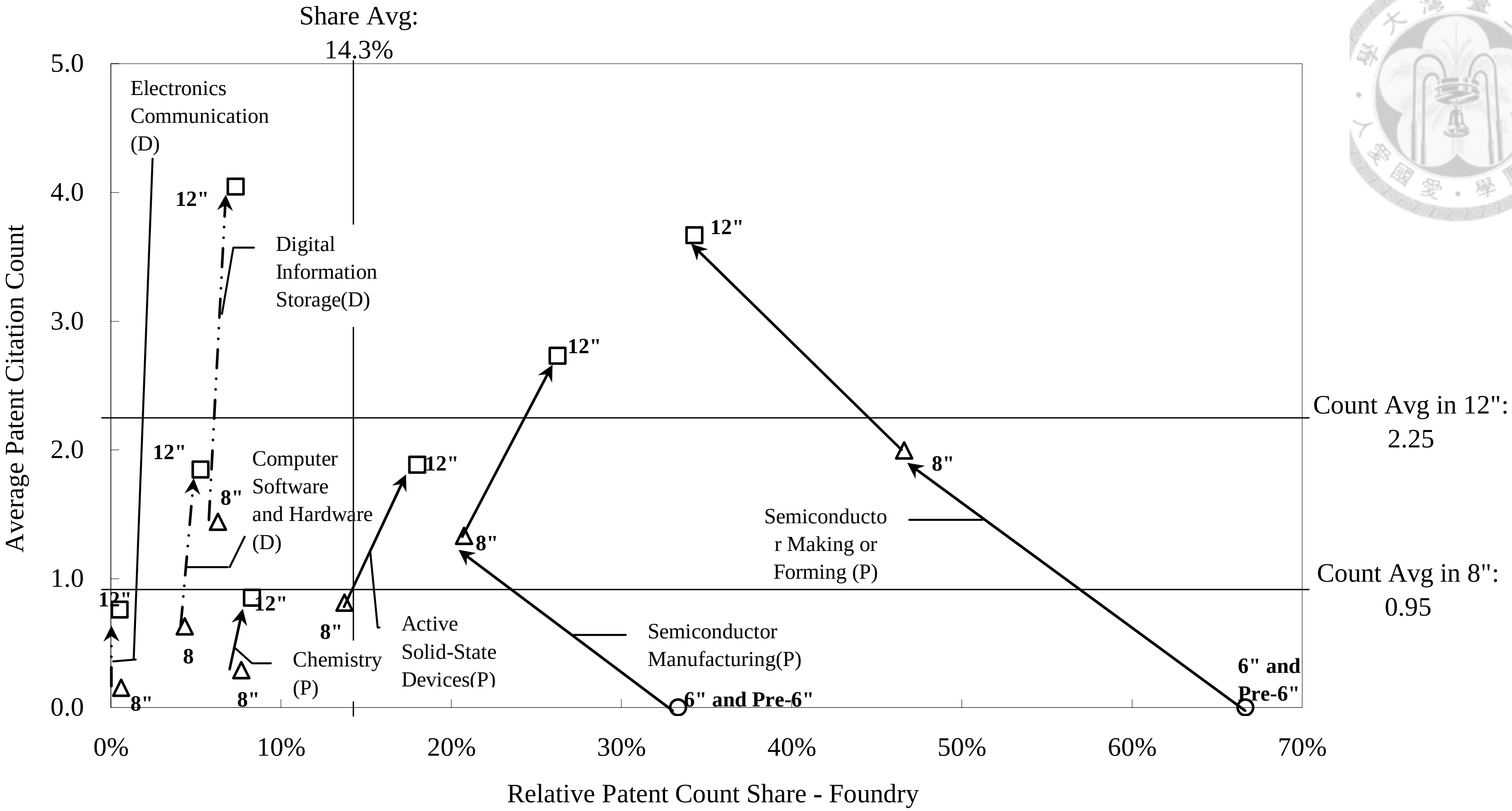


Fig. 4.6: Relative patent count share vs. average patent citation count by wafer size eras and technology fields (Foundry)

4.3.3 IDM

Overall, IDM is moving to the upper right quadrant or the upper left quadrant. That is, IDM is moving to the area of high patent quality and relative patent activity share or to the area of high patent quality but low relative patent activity share. Computer Software and Hardware and Digital Information Storage are two outstanding technology fields for IDM, especially the former. Chemistry and Electronics Communication are technology fields with high average patent citation count but low relative patent count share, as shown in Fig. 4.7.

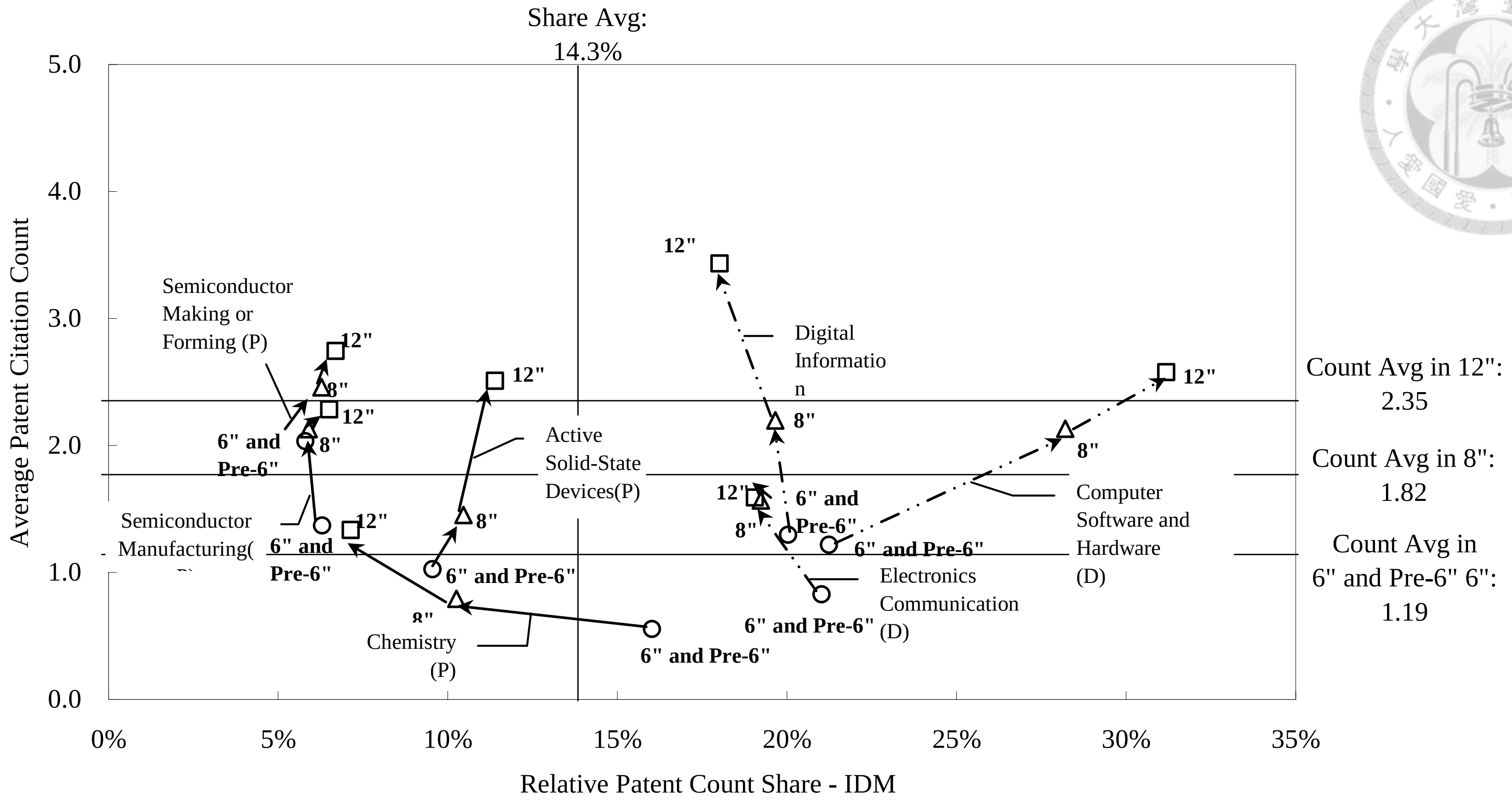


Fig. 4.7: Relative patent count share vs. average patent citation count by wafer size eras and technology fields (IDM)

For the leading technology fields of patent quality by characters, it was found that Design House is good at Digital Information Storage and Semiconductor Manufacturing while Foundry is good at Semiconductor Making or Forming, as shown in Table 4.4. Overall, IDM dominates patent activity while Design House is good at patent quality, as shown in Table 4.4. Computer Software and Hardware and Digital Information Storage are the two major technology fields for IDM and Design House, respectively, and Semiconductor Manufacturing and Active Solid-State Devices are the major technology fields for Foundry although they are non-competitive technology fields for IDM and Design House. This implies that patent shifting or technology shifting is nearly the same for IDM and Design House, which may result from their adopting the so-called Fab-Lite strategy for IDM. It appears that IDM will focus on wafer design and sales rather than wafer manufacturing in the future. Because Foundry made a good profit in the years studied, they invested more not only in the wafer process area but also in the wafer design area, which will enable Foundry to remain a critical character in the value chain.

Combining the results in the paragraph above with those in Section 3.3 reveals that the wafer process patents, which are Foundry's skilled technology fields, are gradually transforming from push patents to pull patents, especially in the 12-inch wafer size era. Thus, the boundaries of character mapping are becoming increasingly vague.

The study created the combination of the patent quality and relative patent activity share as a measurement. From this combination, technology fields could be categorized into the star level, the potential level, the saturated level, or the poor patent level, along with their shifting in different wafer size eras. For example, the shifting for Computer Software and Hardware is on the very positive trend (moving to the upper right quadrant) whereas Chemistry is not as healthy as that of CS, as shown in Fig. 4.5. The combination of the patent quality and relative patent activity share by combining the strategic management function is believed to provide valuable information for the Chief Executive Officer (CEO) or Chief of Technology Officer (CTO) of a company in selecting their most competitive potential patents to develop. It could also provide another perspective for academia to evaluate the character shifting trend in the industry.

Based upon the research results, both IDM and Design House have nearly the same shifting trend for their major technology fields. That is, the technology field shifting of IDM is gradually approaching the pattern of Design House. One of the reasons for this development trend is the Fab-Lite strategy adopted by IDM. To save the capital expenditure on processing equipment, IDM must reduce investments in not only the processing equipment but also in R&D for processing technology fields. In the near future, with the position of the Foundry character on the rise, IDM, the foremost character in the semiconductor value chain for the past 30 years, will be challenged, especially in some specific technology fields. Foundry's technology field development is not limited to wafer process patents but includes wafer design application patents, as shown in Fig. 4.7. Design House's downward trend in patent quality after 8-inch wafer size era is noteworthy as it is the only character markedly declining in the value chain. This development will impact the competitive energy of Design House in the long run and may increase the competition between IDM and Design House.

Traditionally, IDMs needed foundries manufacturing capacities in high demand seasons. However, this situation has shifted over time. Recently, most IDM companies have faced a tough challenge in regards to Design Houses and Foundries in terms of finances, character in the supply chain, and even technologies. They have struggled with the shifting of the overall semiconductor industry. To take advantage of foundries' increasing potential profitability, more and more IDM companies are diversifying or even taking the branch-off route from traditional

IDMs to Foundries. There are many core competences in a successful foundry company. As stated by representatives of the Taiwan Semiconductor Manufacturing Company (TSMC), the world's largest dedicated independent semiconductor foundry, the company's core competences are advanced technology, excellent manufacturing, and customer partnerships. On the other hand, more and more IDM companies have adopted the "Fab-Lite" strategy, coping with dynamic demand uncertainly by retaining a small IC wafer manufacturing capacity and releasing major orders to foundry companies rather than building fabrication plants. This strategy effectively eases the financial burden on the IDMs. This study focuses on the technology elements and applies a patent analysis. Certain IDM companies' greater focus on wafer-process technologies rather than wafer-design application technologies implies that they might be planning to diversify their technology character from IDM to foundry. For example, in 2008 AMD spun off its wafer manufacturing business unit and cooperated with the Advanced Technology Investment from Abu Dhabi to establish the independent chip foundry company, GlobalFoundry. As a supply chain strategy, this is a classic example of competition in the semiconductor industry, in which AMD's industry category shifted from IDM to foundry, and its character shifted from customer and partner (cooperation) to competitor (competition).

4.4 Shifting for Competitive Technology Fields

The shifting of technology by characters is illustrated in the summary of competitive technology fields (defined as technology fields with above average measurements for the average patent citation count), as shown in Table 4.4. It is clear that Design House hit its record high in the 8-inch wafer size era (with five competitive technology fields); IDM remained flat from the 8-inch wafer size era to the 12-inch wafer size era. Foundry is the only character to grow fast from nothing (0/1/3 technology field(s) for 6- and pre 6-inch/8-inch/12-inch). Foundry's shifting trend demonstrated that it acted as not only a manufacturing capacity provider but also a technology contributor.

We also found that the demarcation of each character is becoming vague. For example, Design House contained the competitive technology field Digital Information Storage classified under wafer design application patents, and it also contained Semiconductor Manufacturing classified under wafer process patents in the 12-inch wafer size era. Foundry had the same shifting trend as Design House. IDM is its own character for concurrent shifting in wafer process and design.

In the ANOVA test result, all the data listed in the Table 3.4 are significantly different. The data have been tested by the Post Hoc Test (Scheffe) with the result of significant difference from each other for 12-inch era of Design House, 8-inch era of Foundry, and 6- and pre 6-inch/8-inch/12-inch eras of IDM, as shown in Table 4.4.

Table 4.4: Competitive technology field summary by characters and wafer size eras (average patent citation count)

Character	Wafer Size Era (Avg. Pat. Citation Count -Overall)	Wafer Design Application Patent			Number of Competitive Technology Field (1)	Wafer Process Patent				Number of Competitive Technology Field (2)	Grand Total for Number of Competitive Technology Field (1)+(2)
		Electronics Communication	Computer Software and Hardware	Digital Information Storage		Chemistry	Semiconductor Making or Forming	Semiconductor Manufacturing	Active Solid-State Devices		
Design House	6- and Pre 6-inch (1.19)	0.29	0.50	0.63	0	0.10	0.92	1.45	1.44	2	2
	8-inch (1.84)	2.64	1.53	2.51	2	0.93	2.62	5.93	2.83	3	5
	12-inch ** (2.41)	2.11	2.04	5.33	1	0.68	1.66	4.05	2.29	1	2
Foundry	6- and Pre 6-inch (1.19)	-	-	-	-	-	-	-	-	-	-
	8-inch ** (1.84)	0.15	0.63	1.44	-	0.29	2.00	1.33	0.81	1	1
	12-inch ** (2.41)	0.76	1.85	4.04	1	0.85	3.67	2.73	1.88	2	3
IDM	6- and ** Pre 6-inch (1.19)	0.83	1.22	1.30	2	0.55	2.03	1.37	1.03	2	4
	8-inch ** (1.84)	1.57	2.13	2.20	2	0.79	2.46	2.13	1.45	2	4
	12-inch ** (2.41)	1.59	2.58	3.43	2	1.33	2.74	2.28	2.51	2	4

Note:
** significant at 1% level

4.4.1 Power Shifting by Technical Characters

To study the patent power by characters, we used the patent quality of citations by self and others. Generally speaking, both IDM and Foundry are trending upward whereas Deign House is trending downward in the 12-inch wafer size era, as shown in Table 4.5. In the analysis of the patent quality by self-citation, IDM is the best among the three characters. However, in the analysis of patent quality by others-citation, Foundry is the best among all characters, especially in the latest 12-inch wafer size era. It is apparent that Foundry is a significant winner on patent quality compared to the other characters, and its power and patent quality are increasing gradually. The further results of the ANOVA and Post Hoc Test (Scheffe) show that the data of the 12-inch wafer size era for others-citation are significantly different, as shown in Table 4.5.

Table 4.5: Patent quality by wafer size era and characters
(cited by all/self/others)

Citing Character	Wafer Size Era	Design House	Foundry	IDM
Self	6- and Pre 6-inch	0.23	0.00	1.07
	8-inch	1.59	0.67	1.73
	12-inch	1.56	0.88	2.17
Others	6- and Pre 6-inch	0.43	-	0.01
	8-inch	1.40	0.77	0.11
	12-inch	1.19**	1.85 **	0.25 **
All	6- and Pre 6-inch	0.77	0.00	1.08
	8-inch	2.99	1.44	1.84
	12-inch	2.75	2.73	2.42

Note:
** significant at 1% level

4.4.2 Patent Citation Ratio by Self/Others and Characters

The power of technology as revealed in patents cited by others is one of the most important indexes to measure the technology level. From the study results, the non-self citation ratios of Foundry, Design House, and IDM are 68%, 43%, and 10%, respectively, in the 12-inch wafer size era, as shown in Fig. 4.8. It is clear that Foundry's technology level has been recognized and cited by IDM and Design House significantly, with 68% of others-citation in the 12-inch wafer size era. It is also clear that over 90% of the patents owned by IDM are cited by themselves, as shown in Fig. 4.8. This implies that IDM still regards itself a as technology leader and retains its leading technology position to a certain extent. However, the trend of the self-citation rate decreases from 99% to 90% from the 6-inch and pre 6-inch era to the 12-inch era, showing IDM’s decreasing power.

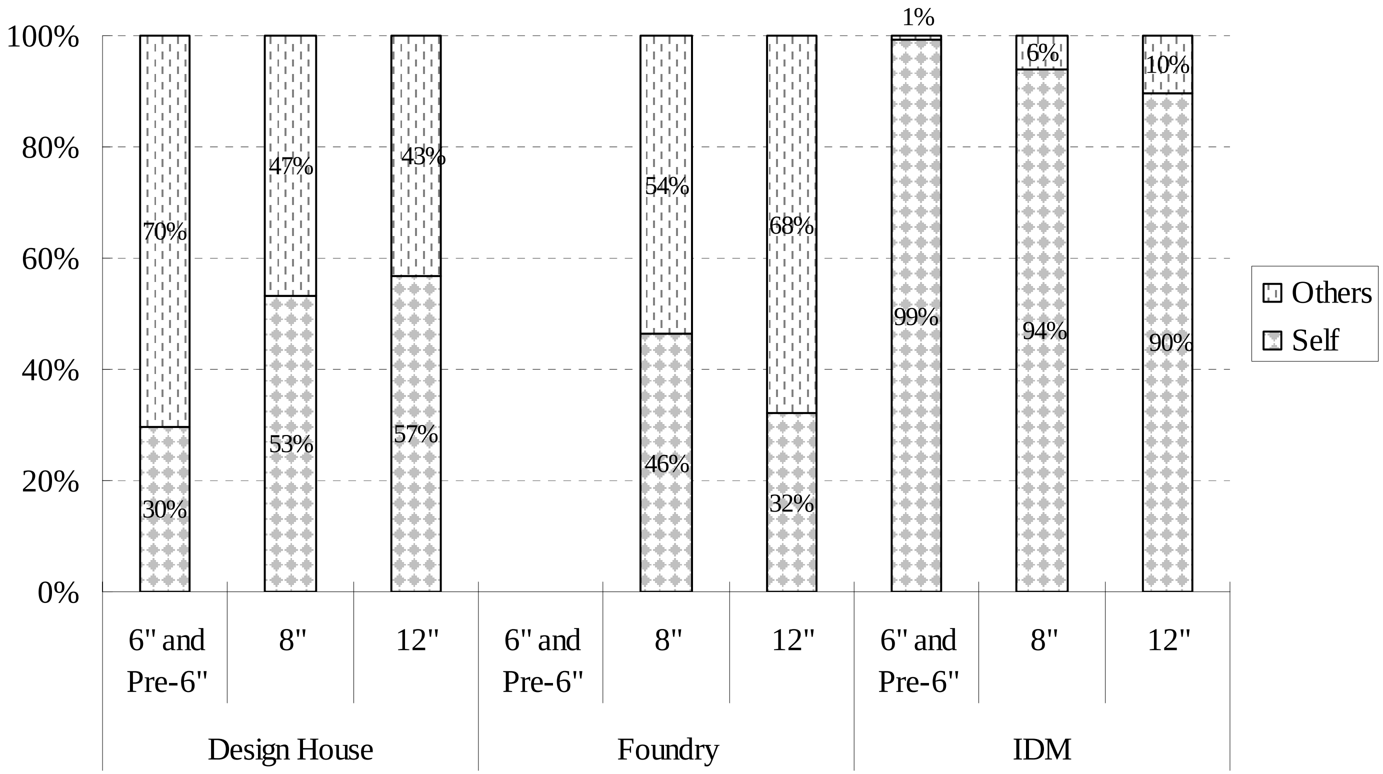


Fig. 4.8: Patent citation ratio by self/others by characters between 1979 and 2009

4.4.3 Patent Citation Network

After investigating the patent citation times of the selected companies, it could be found who cited these patents (self/others) and how many times they cited. Then we built the patent citation network for the semiconductor industry, over the past 30 years for overall analysis and each wafer size era (6-inch/8-inch/12-inch) analysis. Through the presentation of visual map of patent citation network, the relationships among various characters in the industry could be easily perceived. We constructed the patent citation network by patent cited times of each character for different wafer size eras as in Fig. 4.9. Overall, IDM played an important character in patent citation network due to her character as the integration center for the industry value chain. In other words, from the technology point of view, the relationship between IDM and Design House/Foundry is stronger than that between Foundry and Design House.

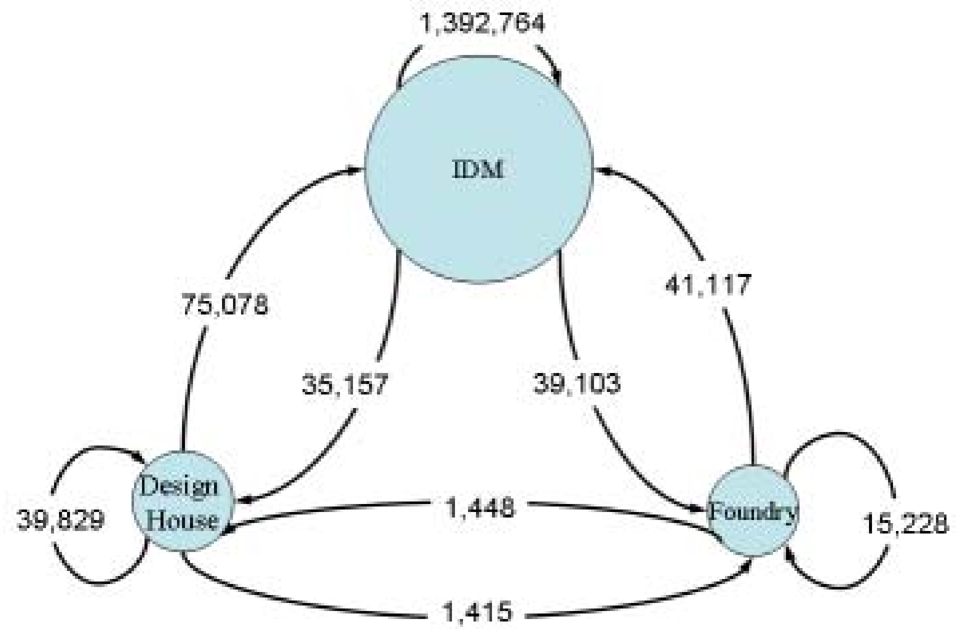


Fig. 4.9: Patent citation network by characters

The patent citation network shifting of each character from 6-inch wafer size era to 12-inch wafer size era is shown in Fig. 4.10-4.12 for details. It appears from the figures that IDM was the integration center among 3 characters no matter in which wafer size era. But, the other 2 characters, Design House and Foundry, also made much progress during these periods.

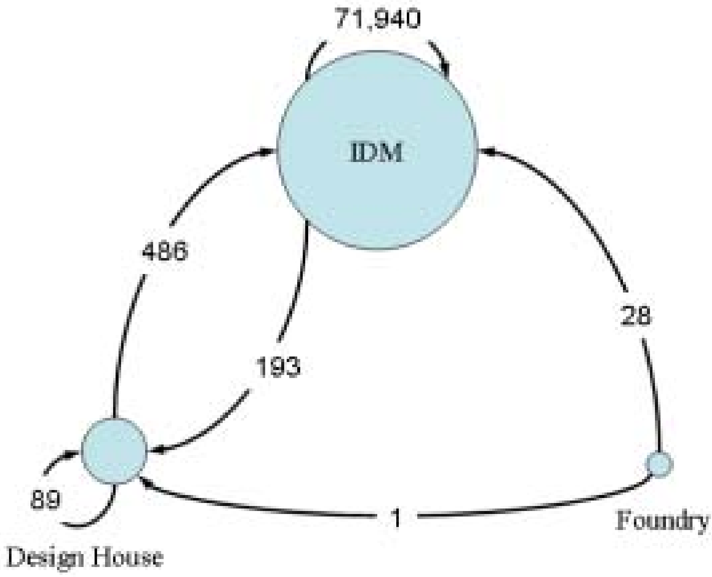


Fig. 4.10: Patent citation network by characters

(6-inch wafer size era)

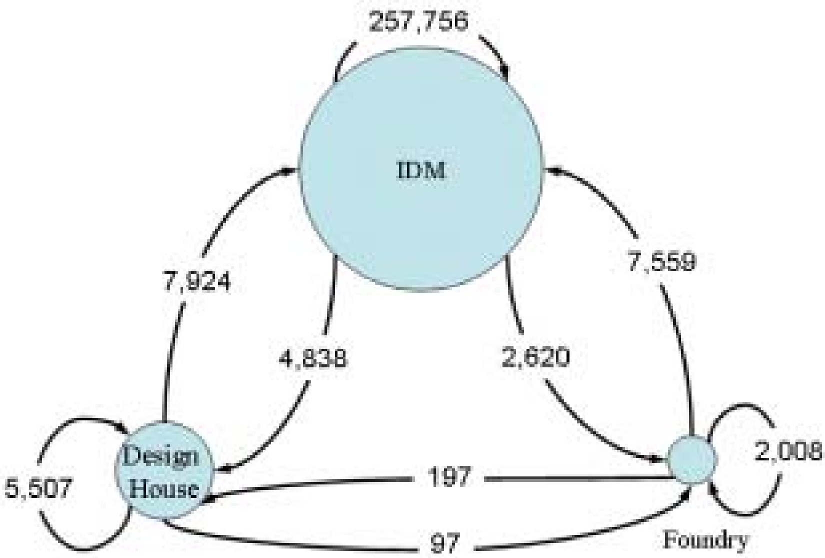


Fig. 4.11: Patent citation network by characters

(8-inch wafer size era)

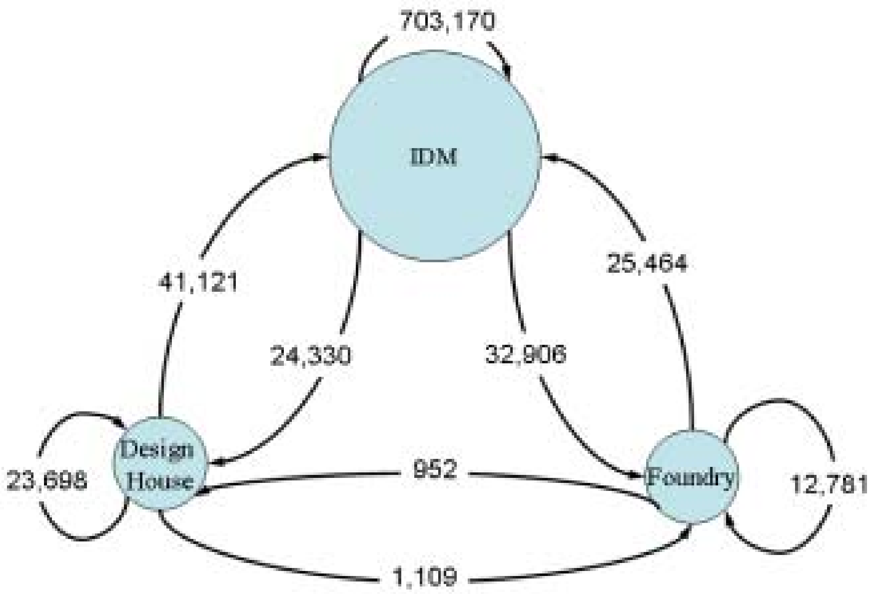


Fig. 4.12: Patent citation network by characters
(12-inch wafer size era)

4.4.4 Competitive Foundry Technology Fields

After analyzing power by patent quality, authors continued to examine the competitive technology fields within the Foundry character during the 12-inch wafer size era. The major Foundry competitive technology fields are Digital Information Storage, Semiconductor Making or Forming, and Semiconductor Manufacturing. The Foundry patent quality (cited by others) in the 12-inch wafer size era is 3.08, 2.37, and 1.82 for Digital Information Storage, Semiconductor Making or Forming, and Semiconductor Manufacturing, respectively, as shown in Table 4.6. Owning these excellent technology fields implies that Foundry is the most important character. This result demonstrated that Foundry's position in the semiconductor value chain is not only a capacity provider but simultaneously a technology contributor. The further results of the ANOVA and Post Hoc Test (Scheffe) show that the data of the 12-inch wafer size era for Digital Information Storage, Semiconductor Making or Forming, and Semiconductor Manufacturing are significantly different.

Table 4.6: Summary for competitive Foundry technology fields by characters and wafer size eras (patent quality by others)

Technology Field	Wafer Size Era	Design House	Foundry	IDM
Digital Information Storage	6- and Pre 6-inch	0.41	-	0.01
	8-inch	1.86	1.02	0.09
	12-inch	1.87 **	3.08 **	0.39 **
Semiconductor Making or Forming	6- and Pre 6-inch	0.75	0.00	0.03
	8-inch	2.28	0.96	0.50
	12-inch	1.27 *	2.37 **	0.44 *
Semiconductor Manufacturing	6- and Pre 6-inch	0.90	0.00	0.05
	8-inch	1.39	0.75	0.41
	12-inch	0.68 **	1.82 **	0.39 **

Note:
* significant at 5% level; ** significant at 1% level

4.5 Hypotheses Testing

In this section, we will clarify the traditional hypotheses in section 1.2.

Hypothesis 1: IDM is a technology giant, in both technology activity and technology quality among the characters in the semiconductor industry.

Clarification 1: For patent activity, IDM, no doubt, dominated the industry. Nevertheless, when considering the shifting of the patent activity (relative count share), IDM is declining, as shown in Fig. 4.4. As to patent quality, IDM's performance is lower than that of Foundry and Design House, especially in the 12-inch wafer size era. In short, the rankings of patent activity and patent quality for IDM are not as good as industry analysts expected.

Hypothesis 2: Foundry excels only at wafer process patents and is not as good at wafer design application patents. Inversely, Design House is familiar with wafer design application patents but is not good at wafer process patents. IDM excels at both wafer process patents and wafer design application patents.

Clarification 2: Foundry naturally performs well at wafer process patents because the major character of Foundry is IC manufacturing. However, the shifting of wafer design application patents in Foundry also performs quite well, as shown in Fig. 4.7. The shifting of Design House shows that most of its technology fields are moving toward the lower right quadrant (saturated level) or the lower left quadrant (poor level) of the combination of patent quality and relative patent activity share, as shown in Fig. 4.6. That is, Design House's technology shifting is not as healthy as Foundry's. IDM's major leading technologies are in wafer design application patents, as shown in Fig. 4.8, but IDM is not a powerful technology leader, based upon the study results.

Hypothesis 3: Wafer design application patents and wafer process patents are regarded as the so-called "Pull" patent type and "Push" patent type, respectively. That is, the wafer design application patents play the leading and major position compared with the wafer process patents.

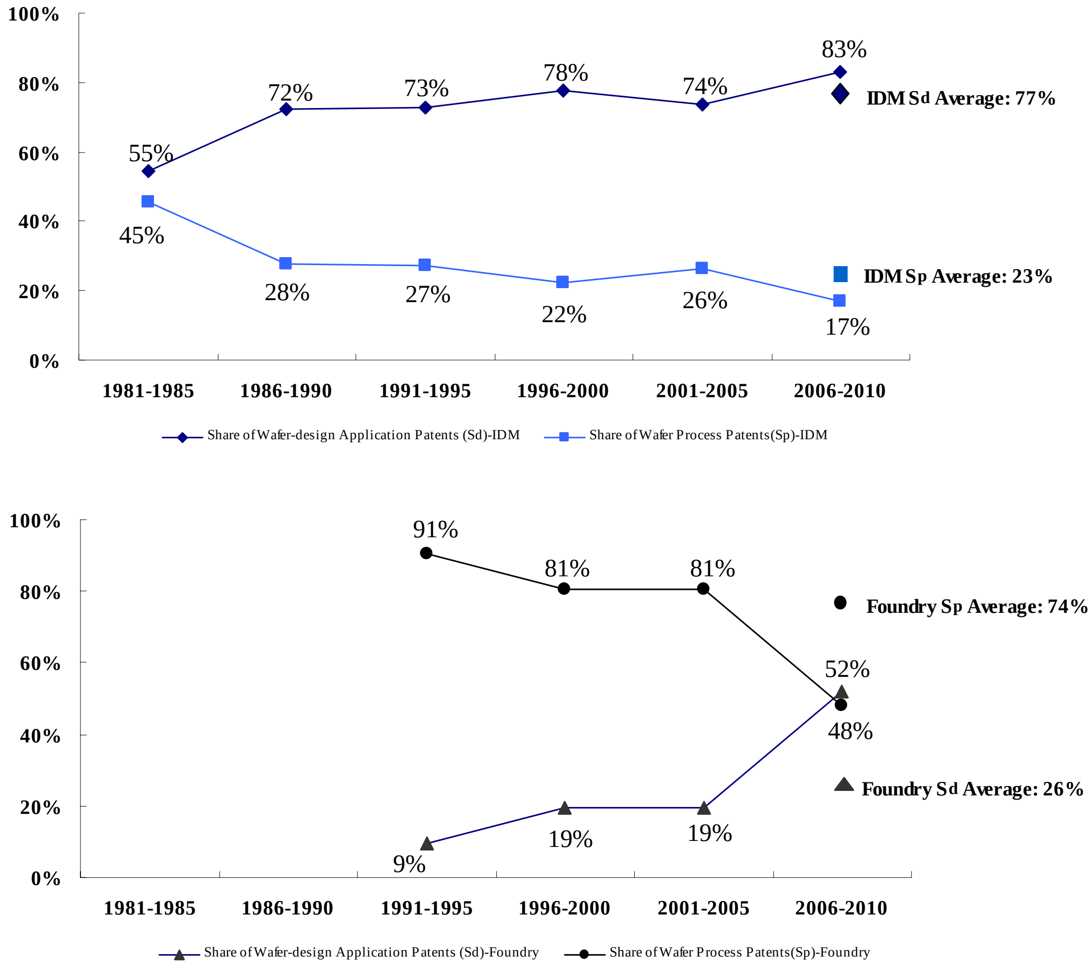
Clarification 3: Overall, the wafer design application patents are the "Pull" patent type and own the leading position compared with the wafer process patents. However, the performance of wafer design application patents is not as good as that of wafer process patents, as shown in Fig. 4.5. From the patent quality perspective (average patent citation count), the wafer process patents achieved an impressive record, as shown in Table 4.3. All the above-mentioned data provide strong evidence that the wafer process patents will become important or even leading characters in the near future.

Chapter 5

Positioning and Shifting of Technology Focus for IDM

5.1 Technology Focus of IDMs and Foundries

From these results, it is clear that the technology focus of IDMs is located at wafer-design application technologies (share of wafer-design application patents, S_d =77%) during the targeted period (1981-2010). On the other hand, the technology focus of Foundries is on wafer-process technologies (S_p =74%). The results are shown in Fig. 5.1. We identified the development trend of wafer-process patents and design application patents for major IDM companies based on this result. Thus, the technology focuses of IDMs and Foundries are wafer-design application and wafer-process respectively. As to technology focus' development trend, the share of wafer-design application technologies for IDM and Foundry companies has been increasing for the past three decades, as shown in Fig. 5.1.



Note: S_p -IDM average (23%) and S_p -Foundry average (74%) were tested by Z-test (Z: 118 >> Z0.025=1.96)

Fig. 5.1: Development trend for IDMs and Foundries by S_d and S_p , 1981-2010

Of the selected IDM companies, IBM dominated the number of patents (P), and Hitachi ranked the second best among the total, as shown in Table 5.1. Most of the technology focuses of the selected IDM companies are on design-application patents (S_d), as the IDM industry showed, but some companies, such as AMD (S_p=46%), Micron (S_p=44%), and TI (S_p=32%), put relatively more resources into the development of wafer-process patents than other IDM companies (IDM Industry S_p=23%) as shown in Table 5.1. Micron (C_p=5105) and IBM (C_p=4494), and AMD (C_p=4039) showed higher total citation counts for wafer-process patents (C_p) as shown in Table 5.1. As to the indices of average patent citation, AMD, TI, and Mitsubishi are the top three companies in AC_d. AMD, TI and Intel, meanwhile, are the top three companies in AC_p, as shown in Table 5.1.

Table 5.1: Summary for patent scorecard of the selected IDM companies, IDM industry, and Foundry industry, 1981-2010

Industry/Company	P	P_d (S_d)	P_p (S_p)	C_d	C_p	AC_d	AC_p
IBM	15410	12938 (84%)	2472 (16%)	21715	4494	1.68	1.82
HITACHI	6819	5596 (82%)	1223 (18%)	9587	2127	1.71	1.74
Micron	6550	3636 (56%)	2914 (44%)	6099	5105	1.68	1.75
Toshiba	5844	4701 (80%)	1143 (20%)	8678	2232	1.85	1.95
NEC	5818	4657 (80%)	1161 (20%)	7994	2263	1.72	1.95
Samsung	5604	3950 (70%)	1654 (30%)	6280	2899	1.59	1.75
Intel	5244	4519 (86%)	725 (14%)	8232	1439	1.82	1.98
FUJITSU	5106	4376 (86%)	730 (14%)	7324	1278	1.67	1.75
MITSUBISHI	4571	3310 (72%)	1261 (28%)	6346	1919	1.92	1.52
AMD	4031	2191 (54%)	1840 (46%)	4532	4039	2.07	2.20
TI	3761	2574 (68%)	1187 (32%)	4978	2502	1.93	2.11
Selected 11 IDM Companies	**68758**	**52448 (76%)**	**16310 (24%)**	**91765**	**30297**	**1.75**	**1.86**
IDM Industry	**104677**	**80195 (77%)**	**24482 (23%)**	**137192**	**44336**	**1.71**	**1.81**
Foundry Industry	**5096**	**1348 (26%)**	**3748 (74%)**	**3897**	**8549**	**2.89**	**2.28**
Total- IDM & Foundry	**109773**	**81543 (74%)**	**28230 (26%)**	**141089**	**52885**	**1.73**	**1.87**

Note: In a descending order according to P (1981-2010) for IDM companies

5.2 Trend of Technology Focus for IDMs

5.2.1 The Productivity and Quality of Technology Focuses on Wafer-design Application (PT_d and QT_d)

The two indices, productivity and quality of technology focuses on wafer-design application (PT_d and QT_d), are shown in Table 5.2. We divided the selected IDM companies into two groups, one being the companies for which PT_d and QT_d are above IDM Average (PT_d =0.75 and QT_d =0.39, 1981-2010), and the other being companies for which PT_d and QT_d are below IDM Average, as shown in Table 5.2. PT_d of the top three companies above the PT_d of IDM Average (Intel, Fujitsu, and IBM) are shown in Table 5.2. The result implies that these IDM companies have significantly higher PT_d in comparison with other IDM companies. That is, Intel, Fujitsu, and IBM have put greater focus on the development of wafer-design application technologies over past three decades than the others did. Meanwhile, AMD, Micron, and TI are the bottom three companies below the PT_d of IDM Average. These selected IDM companies put fewer resources into the development for wafer-design application technologies. In addition to PT_d , the index QT_d is an objective index revealing the quality of patent performance. Regarding QT_d , Micron, AMD, and Intel are the top three companies with higher QT_d than the IDM Average, 0.39, as shown in Table 5.2. This finding implies that the QT_d of these companies is better than that of the other IDM companies with regard to wafer-design application patents. NEC, Fujitsu, and Samsung are the bottom three companies below QT_d of IDM Average, as shown in Table 5.2.

Table 5.2: Summary for PT_d and QT_d of IDM and IDM companies, 1981-2010

Company/Industry (PT_d, QT_d)	**1981-2010**	**1981-1985**	**1986-1990**	**1991-1995**	**1996-2000**	**2001-2005**	**2006-2010**
Intel	(0.90,0.60)	(0.54,0.06)	(0.52,0.24)	(0.73,0.63)	(0.97,1.00)	(0.86,0.62)	(0.93,0.37)
FUJITSU	(0.89,0.29)	(0.38,0.05)	(0.75,0.29)	(0.76,0.33)	(0.91,0.34)	(0.92,0.34)	(0.99,0.15)
IBM	(0.86,0.44)	(0.44,0.07)	(0.77,0.31)	(0.84,0.35)	(0.89,0.67)	(0.85,0.45)	(0.93,0.30)
HITACHI	(0.83,0.33)	(0.46,0.01)	(0.73,0.34)	(0.86,0.39)	(0.84,0.47)	(0.75,0.36)	(1.00,0.20)
Toshiba	(0.81,0.41)		(0.66,0.22)	(0.79,0.35)	(0.78,0.50)	(0.78,0.51)	(0.92,0.32)
NEC	(0.80,0.28)		(0.96,0.25)	(0.84,0.27)	(0.78,0.36)	(0.72,0.27)	(0.93,0.15)
MITSUBISHI	(0.68,0.41)	(0.01,0.02)	(0.52,0.16)	(0.52,0.33)	(0.74,0.56)	(0.78,0.41)	(0.84,0.08)
Samsung	(0.65,0.29)			(0.47,0.20)	(0.65,0.42)	(0.56,0.33)	(0.73,0.23)
TI	(0.62,0.43)	(0.52,0.05)	(0.52,0.41)	(0.44,0.47)	(0.66,0.61)	(0.63,0.46)	(0.74,0.25)
Micron	(0.41,0.82)			(0.00,0.45)	(0.39,0.83)	(0.38,0.85)	(0.54,0.78)
AMD	(0.39,0.66)	(0.33,0.00)	(0.37,0.17)	(0.57,0.55)	(0.52,0.81)	(0.30,0.67)	(0.51,0.46)
IDM Average	(0.75,0.39)	(0.40,0.04)	(0.68,0.27)	(0.69,0.33)	(0.76,0.54)	(0.70,0.43)	(0.85,0.28)
Foundry Average	(0.19,0.52)			(0.00,0.22)	(0.12,0.59)	(0.12,0.55)	(0.52,0.47)

Note: In a descending order according to PT_d (1981-2010)

The PT_d and QT_d for major IDM companies and all IDM companies were also tested by Z-test with a 95% confidence interval, which determined whether the ratios between major IDM companies and all IDM companies are statistically different.

The two-dimensional method is applied to detect the position and development trend for wafer-design application technology. The position of the selected IDM companies in wafer-design application technologies is classified by IDM's PT_d (0.75) and QT_d (0.40), as shown in Fig. 5.2. Intel, IBM, and Toshiba performed well significantly both in PT_d and QT_d. That is, these three companies retained competences on wafer-design application technologies. On the other end, Samsung performed relatively poorly in both PT_d and QT_d. It is clear that Samsung put fewer resources on the wafer-design application technologies. Meanwhile, Micron, AMD, and TI are three companies located in the upper-left area (Foundry-oriented area), as shown in Fig. 5.2.

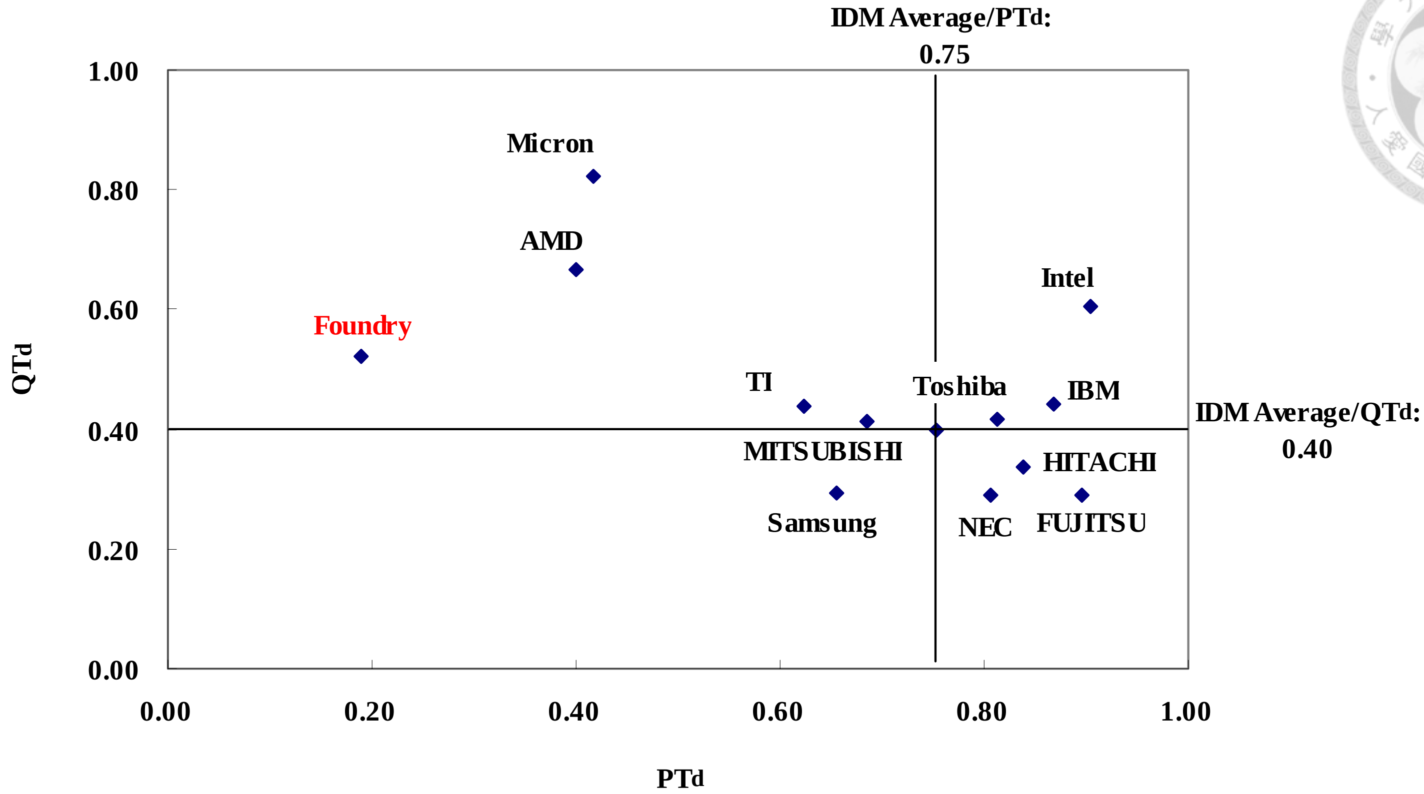


Fig. 5.2: Position of PT_d and QT_d IDM companies and Foundry, 1981-2010

To more easily clarify among the selected IDMs, we divided them into three groups to explore their development trends in PT_d and QT_d. The three groups are above (Intel), closed (NEC), and below (AMD) PT_d of IDM Average respectively, as shown in Fig. 5.3. Generally speaking, the development trend of technology focus on wafer-design application technologies for IDM has moved to the upper-right area, high PT_d and QT_d. This implies that most IDM companies put more resources into the wafer-design application technologies with high quality. However, compared with the prosperous development trend of PT_d, QT_d has been in recession since 2000. For the selected IDM companies for which PT_d are above IDM Average, Intel has the most significant performance in both PT_d and QT_d, as shown in Fig. 5.3. As to the selected IDM companies for which PT_d is below IDM Average, AMD has a relatively stronger performance in QT_d, as shown in Fig. 5.3.

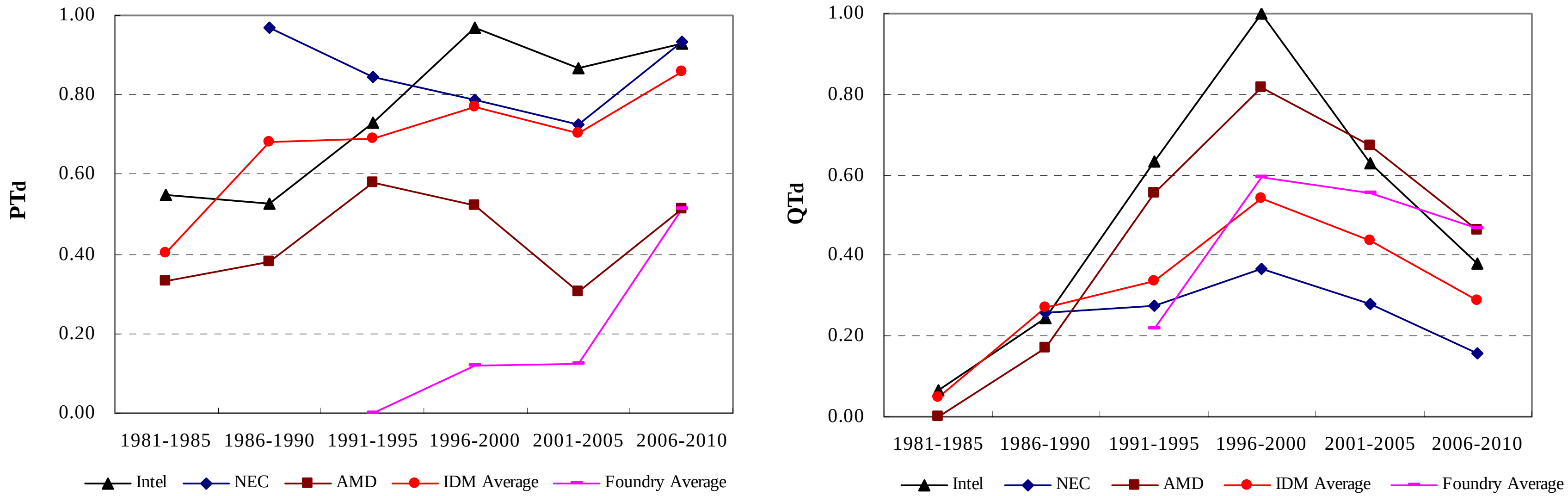


Fig. 5.3: Development trend of PT_d and QT_d of IDM companies, IDM Average, and Foundry Average during 1981-2010

5.2.2 The Productivity and Quality of Technology Focus for Wafer-process Technology (PT_p/QT_p)

After assessing the PT_d and QT_d, we evaluated another technology focus, wafer-process technologies, by PT_p and QT_p for the selected IDM companies. These two indices are shown in Table 5.3. We divided the selected IDM companies into two groups: one being companies for which PT_p and QT_p are above IDM Average (0.24/0.44, 1981-2010) and the other being companies for which PT_p and QT_p are below IDM. Regarding QT_p, AMD, Micron and TI are the top three companies above the QT_p of IDM, as shown in Table 5.3. This implies that these companies perform differently from other IDM companies in QT_p. That is, AMD, Micron and TI put greater focus on the development of wafer-process technologies over past three decades than the others did. Intel, FUJISTU, and IBM, are the bottom three companies in QT_p. These companies put fewer resources into the development of wafer-process technologies. On the other hand, Micron, AMD, and Intel are top three companies in QT_p, which implies that the quality of these companies in wafer-process technologies is clearly recognized, as shown in Table 5.3.

Table 5.3: Summary for PT_p and QT_p of IDM companies, IDM average, and Foundry average, 1981-2010

Company/Industry (PT_p, QT_p)	1981-2010	1981-1985	1986-1990	1991-1995	1996-2000	2001-2005	2006-2010
AMD	(0.60,0.58)	(0.66,0.00)	(0.62,0.48)	(0.42,0.42)	(0.47,0.67)	(0.69,0.61)	(0.48,0.32)
Micron	(0.58,0.79)			(1.00,0.54)	(0.60,0.70)	(0.61,0.75)	(0.45,1.00)
TI	(0.37,0.51)	(0.47,0.21)	(0.47,0.32)	(0.55,0.36)	(0.33,0.68)	(0.36,0.71)	(0.25,0.33)
Samsung	(0.34,0.37)			(0.52,0.43)	(0.34,0.49)	(0.43,0.47)	(0.26,0.21)
MITSUBISHI	(0.31,0.25)	(0.98,0.12)	(0.47,0.15)	(0.47,0.23)	(0.25,0.28)	(0.21,0.33)	(0.15,0.07)
NEC	(0.19,0.38)		(0.03,0.22)	(0.15,0.29)	(0.21,0.51)	(0.27,0.35)	(0.06,0.16)
Toshiba	(0.18,0.38)		(0.33,0.41)	(0.20,0.33)	(0.21,0.51)	(0.21,0.39)	(0.07,0.17)
HITACHI	(0.16,0.33)	(0.53,0.15)	(0.26,0.29)	(0.13,0.45)	(0.15,0.36)	(0.24,0.39)	(0.00,0.15)
IBM	(0.13,0.43)	(0.55,0.24)	(0.22,0.35)	(0.15,0.34)	(0.10,0.47)	(0.14,0.55)	(0.06,0.32)
FUJITSU	(0.10,0.29)	(0.61,0.12)	(0.24,0.27)	(0.23,0.30)	(0.08,0.33)	(0.07,0.35)	(0.00,0.18)
Intel	(0.09,0.54)	(0.45,0.27)	(0.47,0.38)	(0.26,0.41)	(0.02,0.73)	(0.13,0.69)	(0.06,0.34)
IDM Average	(0.24,0.44)	(0.59,0.19)	(0.31,0.29)	(0.30,0.34)	(0.23,0.50)	(0.29,0.53)	(0.14,0.37)
Foundry Average	(0.81,0.65)			(1.00,0.40)	(0.88,0.77)	(0.88,0.66)	(0.48,0.34)

Note: In a descending order according to PT_p (1981-2010)

In terms of the positioning of the selected IDM companies by the two-dimensional method (IDM Average PT_p = 0.25 and QT_p = 0.45), Micron, AMD, and TI are located in the upper-right area (Foundry-oriented area), as shown in Fig. 5.4. These companies have significant performance in both PT_p and QT_p. Companies including Fujitsu, Hitachi, and IBM have worse performance in both PT_p and QT_p.

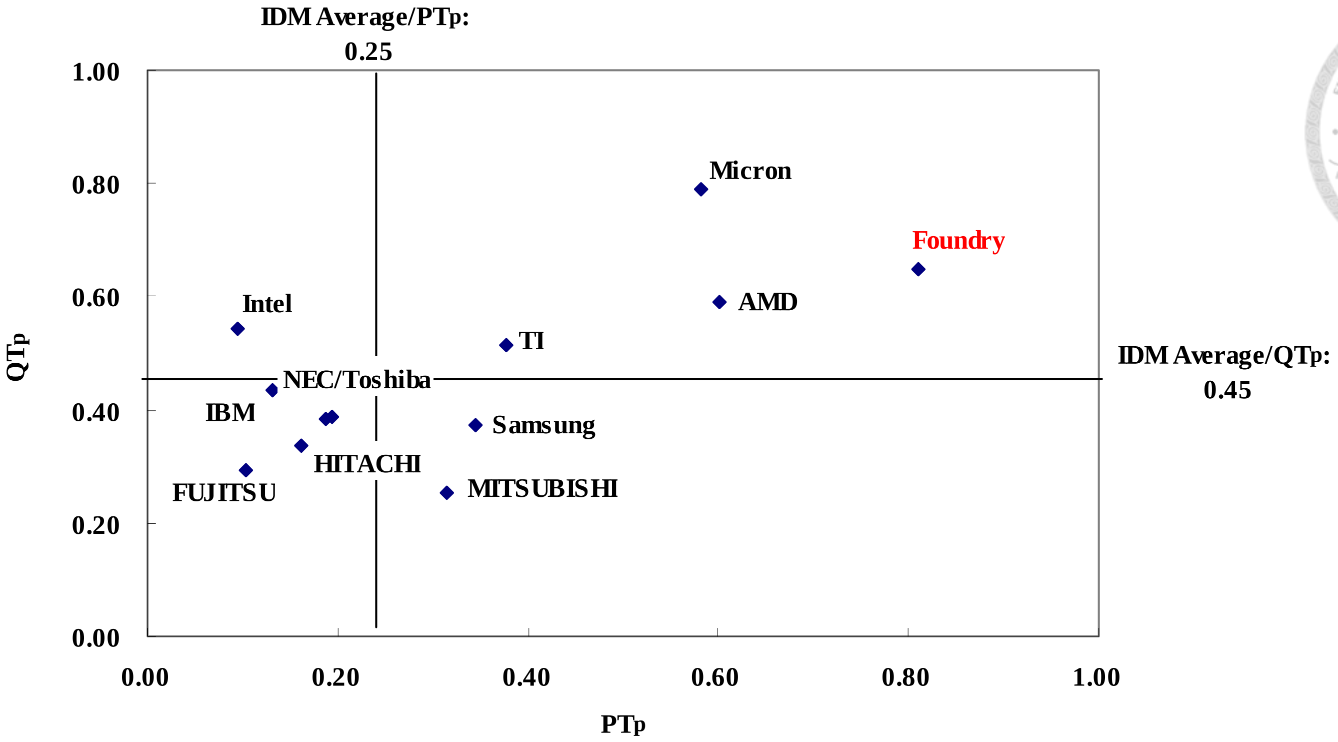


Fig. 5.4: Position of PT_p and QT_p of IDM companies and Foundry during 1981-2010

To more easily clarify the selected IDM companies, we also divided the selected IDM companies into three groups to explore the development trend of PT_p and QT_p of the selected IDM companies. The three groups are above (AMD), closed (NEC), and below (Intel) PT_p of IDM respectively, as shown in Fig. 5.5. Most IDM companies have moved toward the upper-right area, which means these companies have high QT_p but low PT_p, as shown in Fig. 5.5. The development trend is different from that of PT_d and QT_d. That is, the productivity of technology focuses on wafer-process technology is low but their quality is recognized, except for that of some companies such as AMD. The development trend of AMD is different from most IDM companies. It invested more resources into the development of wafer-process technologies than most of the other selected IDM companies did, as shown in Fig. 5.5. AMD maintained nearly the same productivity trend of technology focus on wafer-process patents with the other IDM companies during 1981 to 1990; however its pattern shifted after 1991. In short, AMD put more resources into the development of wafer-process technologies after 1991. In addition to AMD, Intel has also high recognition in terms of QTp, as shown in Fig. 5.5.

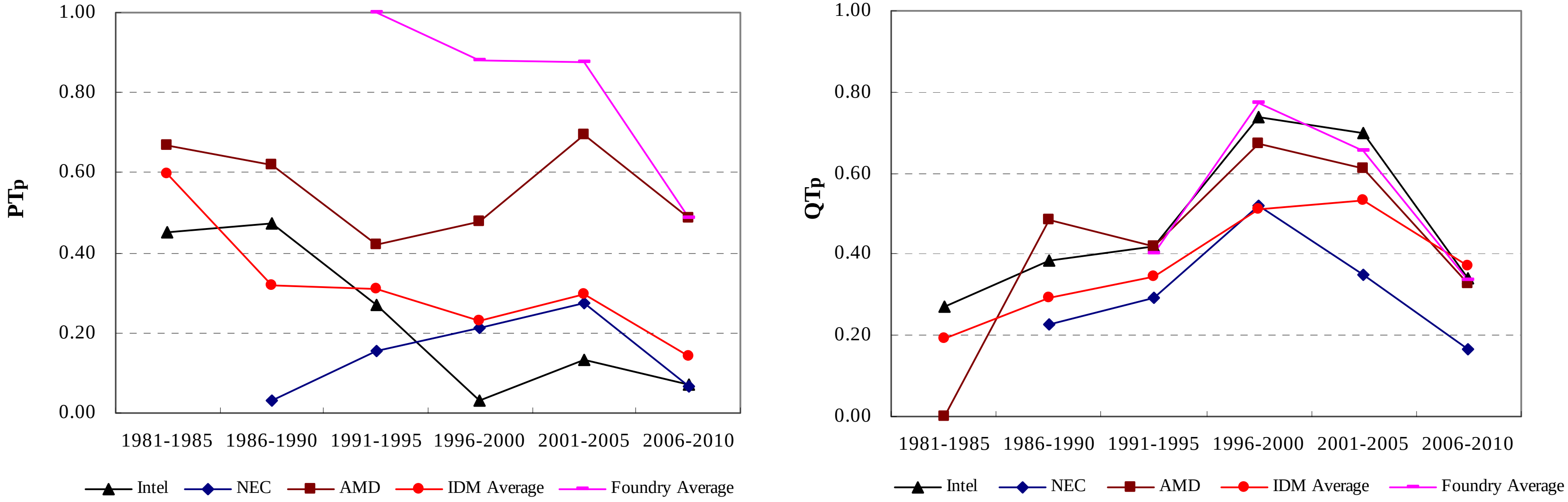


Fig. 5.5: Development trend of PT_p and QT_p for IDM companies, IDM average, and Foundry average during 1981-2010

5.2.3 Detection of Technology Focus Shifting

(a) An integrated result from L_d & L_p

From the synthesis (L_d and L_p) point of view, the position and development trend of the selected IDM companies are shown as Fig. 5.6 and Fig. 5.7 respectively. Micron and Intel performed significantly in both L_d and L_p, as shown in Fig. 5.6. That is, Micron and Intel invested almost equal resources into the development of wafer-design application technologies and wafer-process technologies; meanwhile, the quality of these two technologies was also recognized. AMD and TI, located in the lower-right area (Foundry-oriented area), have high L_p but low L_d, as shown in Fig. 5.6. AMD and Intel invested more resources and got higher recognition in wafer-process technologies than in wafer-design application technologies. That is to say, the position of these companies is in the Foundry-oriented area. This implies that AMD and Intel are in more competitive positions to join Foundry business. Some companies, such as Fujitsu and Toshiba, are positioned in the upper-left area, which means these companies have high L_d but low L_p, as shown in Fig. 5.6. This implies that these companies are positioned in the same place as most IDM companies. In fact, some Japanese companies, HITACHI, MITSUBISHI and NEC, positioned in the lower-left area, have merged to be another company, Renesas Electronics Corporation in 2002. It reflects somewhat that these Japanese companies preformed poor on the semiconductor manufacturing gradually.

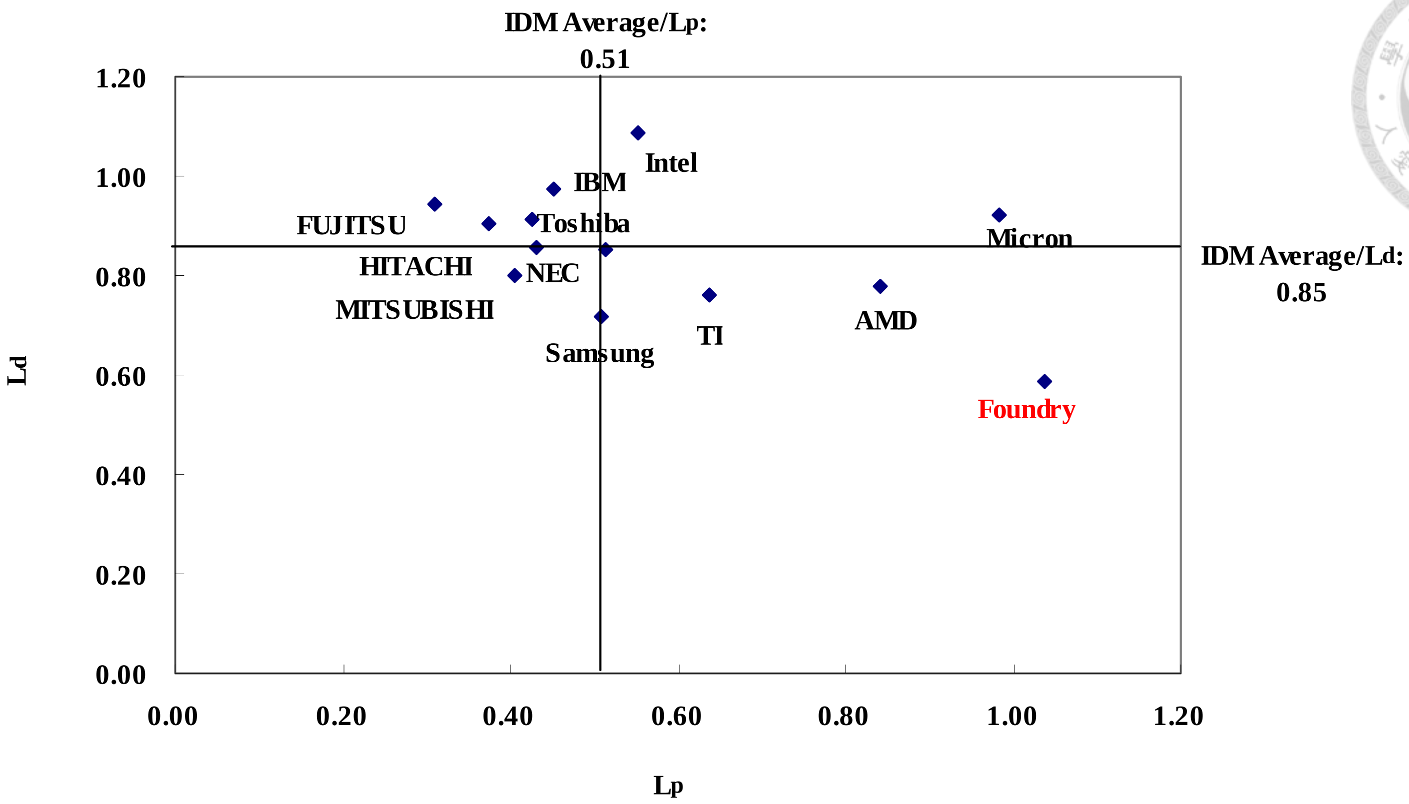


Fig. 5.6: Position of L_p and L_p of IDM companies and Foundry during 1981-2010

As to the development trend of the integrated view by L_d and L_p, we also divided the selected IDM companies into three groups. The three groups are above (Micron), closed (Samsung), and below (Fujitsu) L_p of IDM Average (0.51, during 1981-2010, as shown in Fig. 5.6.) respectively, as shown Fig. 5.7. In general, the development trends of most IDM companies vary across different periods over past three decades. Most IDM companies possessed high L_d but low L_p in the early stage, 1981-1985. In the middle stage, they possessed high L_d and high L_p. And during the late stage, they possessed high L_p but low L_d, being Foundry Average-oriented. It implies that IDMs' technology focuses and quality have shifted from wafer-design application technologies to wafer-process technologies over the past three decades. Of the selected IDM companies, Micron and Samsung have moved from high L_d/low L_p toward high L_p/high L_d, as shown Fig. 5.7, indicating that these two have put more resources into the development of wafer-process technologies with high quality recognition, thus keeping high positions in L_d. AMD has shifted from low L_p and L_d toward high L_p but low L_d, implying that AMD has also gradually put more resources into the development of wafer-process technologies. Of the companies with lower L_p of IDM, Fujitsu has shifted from high L_p/low L_d to high L_d/low L_p as shown Fig. 5.7. That is to say, Fujitsu should put more resources on the development of wafer-design application technologies.

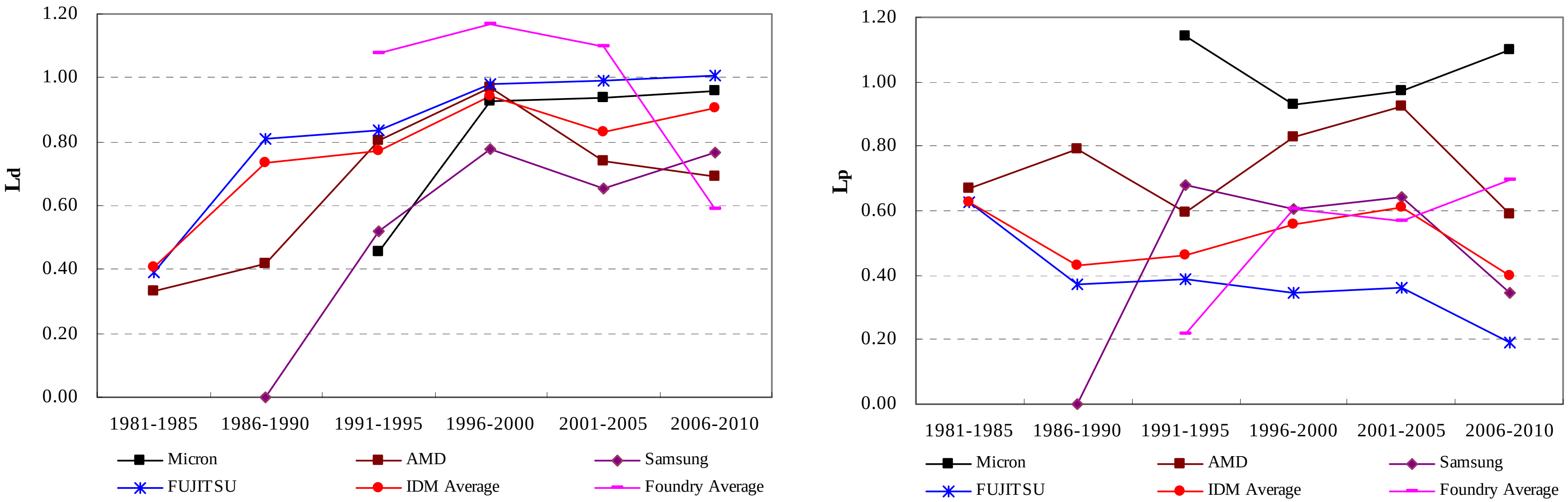


Fig. 5.7: Development trend for L_d and L_p for IDM companies, IDM average, and Foundry average during 1981-2010

(b) Summary of the productivity and quality of technology focuses (PT_d / PT_p , QT_d / QT_p), and the length from the origin by wafer-design application patents and wafer-process patents (L_d / L_p)

From the point of view of L_d and L_p, it is clear that the technology focuses of IDMs and Foundries are on wafer-design application technologies and wafer-process technologies respectively. Micron, AMD, TI, and Intel have higher L_p than most IDM companies (IDM Average L_p =0.51), as shown in Table 5.4. That is, these companies, with competitive advantages, are well-positioned to join the Foundry business (Foundry Average L_p =1.04) should they desire to. More and more IDM companies have officially claimed to join the Foundry business, such as AMD, Samsung, Intel and IBM. We verified their L_p, and AMD has the most significant performance in this regard. Thus, AMD holds a better position in comparison with other companies should it plan to join the Foundry business. From the point of view of L_d / L_p, Micron is a character model, showing significant performance in both wafer-design application technologies and wafer-process technologies. In short, Micron can play an important character in both IDM and Foundry technologically speaking.

Table 5.4: Summary of PT_d / QT_d, PT_p / QT_p and L_d / L_p of IDM companies, IDM Average, and Foundry Average during 1981-2010

Company/Industry	PT_d	QT_d	L_d	PT_p	QT_p	L_p
Micron	0.42	0.82**	0.92	0.58	0.79**	0.98
AMD	0.40	0.67**	0.78	0.60	0.59**	0.84
TI	0.62	0.44	0.76	0.38	0.51	0.64
Intel	0.90	0.61**	1.09	0.10	0.54	0.55
Samsung	0.66	0.29**	0.72	0.34	0.37	0.51
IBM	0.87	0.44	0.97	0.13	0.43	0.45
NEC	0.81	0.29**	0.86	0.19	0.39	0.43
Toshiba	0.81	0.42	0.91	0.19	0.38	0.43
MITSUBISHI	0.69	0.41	0.80	0.31	0.25**	0.40
HITACHI	0.84	0.34	0.90	0.16	0.34	0.37
FUJITSU	0.90	0.29	0.94	0.10	0.29**	0.31
IDM Average	0.75	0.40	0.85	0.25	0.45	0.51
Foundry Average	0.19	0.52	0.55	0.81	0.65	1.04

Note:
1. The data are sorted by L_p
2. ** Significant at 1% level

From the ANOVA test result, the PT_d/PT_p, QT_d/QT_p, and L_d/L_p of the targeted IDM companies are significantly different. The data have also been subjected to post hoc (Scheffe) testing, with a result showing significant differences among them.

This study detected the position and position shifting of technology focus for the selected IDM companies from a patent perspective. For individuals who make the technology development and character decisions in companies, this study could provide a comprehensive picture for detecting relative competitiveness between their company and competitors (or the industry average) in the semiconductor industry. For industry researchers, this study could be applied to other industries to detect the overall picture of the corporate business decisions of targeted companies in the early (development) stage through patent analyses. There is a strong link between IDM companies, such as AMD, which officially announced entering the foundry business, and the shift of technology focus. For other IDM companies that have not officially announced their intention to migrate or branch off as foundry companies, such as Micron and TI, shifting positions in technology focus hints that their strategy has changed. Thus, as Micron and TI have put more resources into the technology development required for the foundry business, we can expect that these IDM companies may adopt that strategy.

Based on these findings, we suggest that patents not only express company technology capability, but also imply business strategies. Industry practitioners could apply this analytical model to detect positions and position shifts in technology focus. From an integration point of view (L_d/L_p), both AMD and TI are located in the Foundry-oriented area (lower-right area, high L_p but low L_d, as shown in Fig. 5.6). In early 2009, AMD was one of the most typical examples of a company taking practical steps toward establishing a pure foundry company, as it did with GlobalFoundry (Reuters, 2009). Therefore, from a patent perspective, AMD may have significantly shifting its technology character. Other IDM companies, such as Micron, have also shown significant performance in those criteria without officially announcing their intent to enter the Foundry business, which perhaps indicates their intention to make the decision to change. Our result interprets the messages that certain IDM companies have sent by shifting their technology focus from wafer-design application technologies (IDM oriented) to wafer-process technologies (Foundry oriented). Whether or not these selected IDM companies have announced a technology character shift, their technological readiness is stronger than that of other IDM companies if they plan to migrate to the foundry business. If companies can analyze other's patents based on this working framework, their decision makers will have business intelligence through which they will be better equipped to cope with changes in the strategies of their competitors, and even their partners, at the earliest stage. The actual strategic actions of these companies reflect on the map of positioning for integrated results, as shown in Fig.5.6. For example, AMD was a typical IDM company before 2008 and acted traditionally as a foundry's customer or partner, particularly in the high-demand season. When AMD spun off its manufacturing function (fab) as an independent corporation, it became a competitor to other foundry companies, such as TSMC. From the supply chain point of view, it is a classical example for co-opetition of semiconductor industry shown in Fig. 5.8. In other words, the position of AMD changed from IDM to Foundry, and it is the character changing from the customer and partner (Cooperation) to the competitor (Competition). Foundry companies with advance business intelligence of current IDM customer and partner patent trends could reduce the impact of strategy changes by adapting their own technologies, human resources, financial aid, and other factors in preparation.

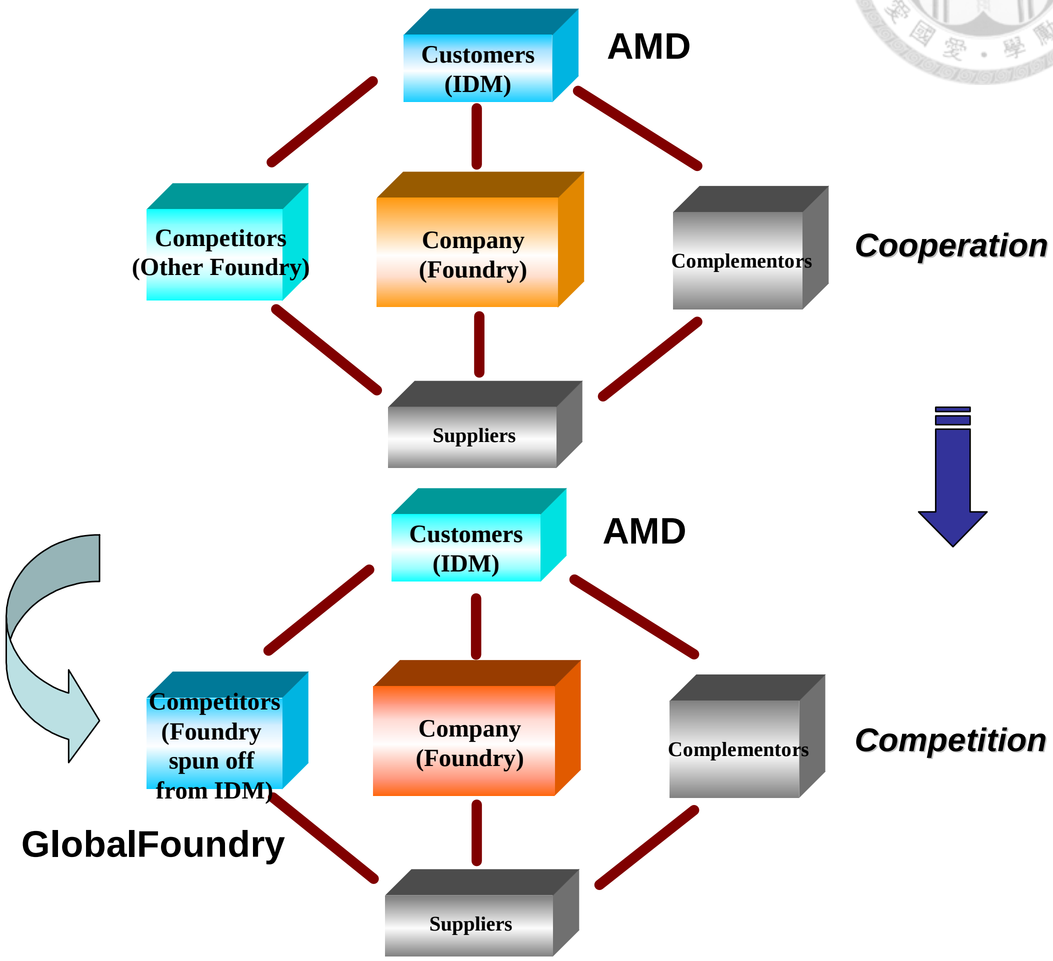


Fig. 5.8: AMD’s value net for co-opetition (from Brandenburger and Nalebuff, 1996).

In addition to the character shifting between IDM and Foundry, the classic example of the co-opetition model is Apple and Samsung. Apple and Samsung may be battling each other in the courts over patent claims but the two companies are still working with each other on the technology for the next iPhone. Samsung and Intel are other companies that openly took action to join the Foundry business. The position of technology focus for these companies kept them well positioned in both wafer-process and wafer-design application technologies. Samsung openly announced its plans to join the Foundry business in 2004 and aggressively grasped the orders of Apple Inc. over the past two years (Reuters, 2009). The announcement from Samsung in 2004 reflects the rising trend of the integrated measurement of wafer-process technologies (L_p) after 1990, as shown in Fig. 5.7. In contrast to Samsung, Intel delayed announcing its plan to join the Foundry business until 2010 and focused more on specific or advanced technologies of the Foundry business (EETimes, 2008). The actions of Intel display how the company has prepared well in terms of both the integrated measurement of wafer-design application and wafer-process technologies (L_d and L_p), as shown in Fig.5.6 (locating in the upper-right area). Some companies, such as Fujitsu and Mitsubishi, retained their positions, as did most IDMs. These companies still played their traditional characters. The actions of Fujitsu and Mitsubishi aligned with the results shown in Fig. 5.6, demonstrated that it performed well only in the integrated measurement of wafer-design application technologies and not in wafer-process technologies. We attempted to implement a working model from the patent perspective that is applicable to other industries with regard to shifting of technology character. This study’s results also provide a strategic map of competitive analysis for industry practitioners in mutual positions in patent perspectives. There are some limitations of using patent data in research. For example, not all technologies or inventions are patented because of strategic concerns or under patentability criteria of the USPTO. Besides, the patent data were queried only from USPTO excluding other areas such as European, Japan, and China. It may affect the research completeness for specific fields.

5.3 Patent Citation Trend for IDMs with Willingness to Join Foundry Business

After evaluated PT_d / PT_p, QT_d / QT_p, and L_d / L_p, we selected 4 IDMs with willingness to join Foundry business (AND, IBM, Intel, and Samsung) to assess their average patent citation count by Foundry companies during 1991-2010. Different form QT_d / QT_p, we discussed their average citation count by Foundries according to wafer-process technology and design-application technology.

5.3.1 Development Trend of Average Patent Citation Count of IDMs for Wafer-process Technology

AMD hit its record high on wafer-process technology during 1996-2000. That is, AMD's patent quality for Foundry business was high after 1996. The development trend of the average patent citation count by Foundries all hit their record high during 1996-2000 among 4 IDMs. IBM is one of the lowest patent qualities from the average citation count point of view, as shown in Fig. 5.9.

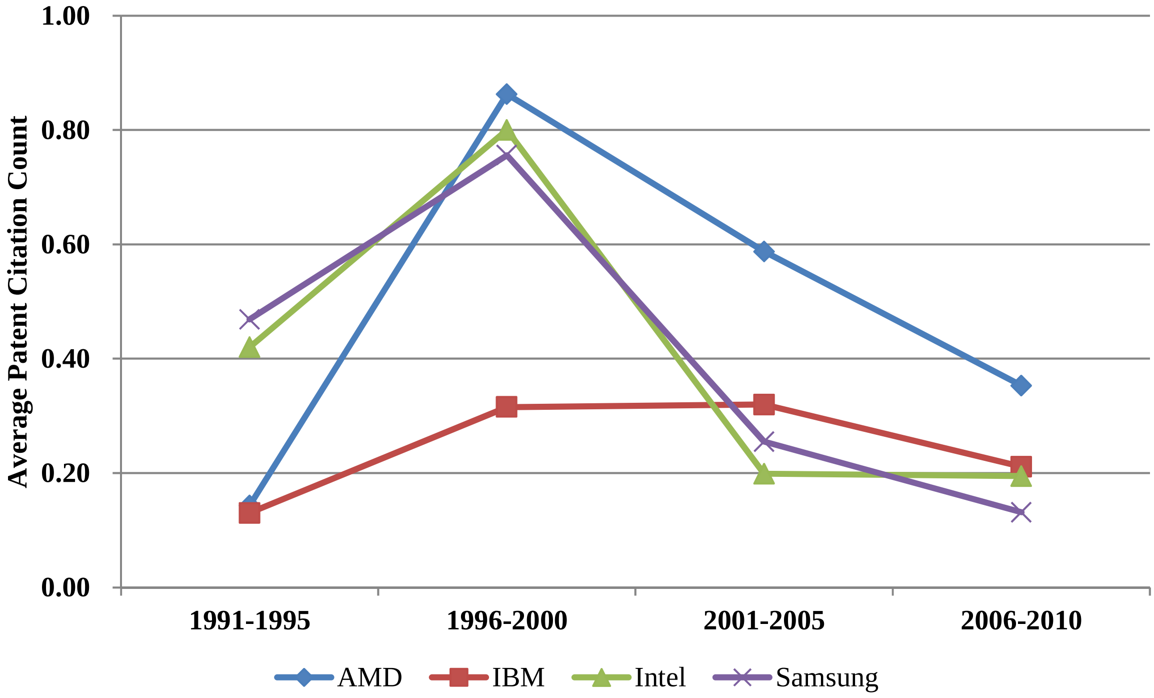


Fig. 5.9: Trend of average patent citation count by Foundry for selected IDMs.

(wafer-process technology)

5.3.2 Development Trend of Average Patent Citation Count of IDMs for Wafer-design Application Technology

As to the development for wafer-process technology, AMD kept the leading position during targeted period, 1991-2010. It implied that AMD's performed high patent quality for Foundries no matter on wafer-process technologies or wafer-design application technologies, as shown in Fig. 5.10. Samsung performed well after 2005, as shown in Fig. 5.10.

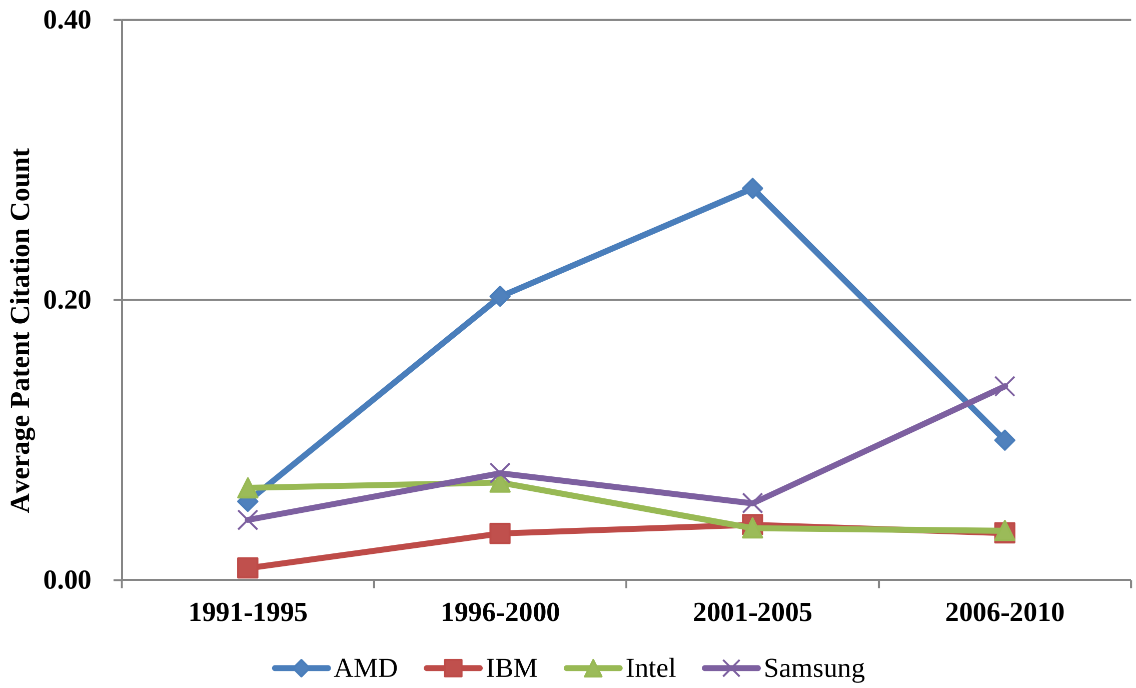


Fig. 5.10: Trend of average patent citation count by Foundry for selected IDMs.

(wafer-design application technology)

5.3.3 Discussion for Development Trend of Average Patent Citation Count for IDMs

Generally speaking, AMD showed high impact power for Foundries, especially on wafer-process technologies (Foundry-oriented). Samsung As to the development for wafer-process technology, AMD kept the leading position during targeted period, 1991-2010. It apparently got high recognition after 2000 but it did not announced to join Foundry business until 2008. That is, AMD prepared well in the early stage for the change. Samsung is another IDM with strong intention to join Foundry business. We can catch the ambition from Fig. 5.9

and Fig. 5.10. Among selected IDMs, IBM’s intention is not so clear from the average citation count point of view.

Chapter 6

Conclusions and Implications

6.1 Conclusions

Based on the study's results, there are several conclusions for the research.

(a) Foundry companies have been technology transferors rather than merely manufacturing capacity providers

Foundry is regarded as the manufacturing capacity provider in the semiconductor industry value chain traditionally. As to the technology aspect, IDM is considered the technology donator and dominator. But, the situation for the semiconductor industry has changed recently. Based on the research result of the study, it is found that Foundry companies have been the technology transferors gradually rather than been the manufacturing capacity providers only. Character playing in the semiconductor industry value chain has changed with different technology eras, especially for IDM and Foundry.

(b) Foundry companies are not only good at wafer-process technologies but also good at wafer-design technologies

The technology development of Foundry companies are healthy both on technologies of wafer-process and wafer-design application from the research result. It inheres that the impact power of Foundry is getting deeper and even threatens the other 2 characters, IDM and Design House. One of the major reasons is the fact that IDM and Design House cooperated closely with Foundry to save their expenditure on R&D and then raised the technology level of Foundry for past 2 decades.

(c) The actual strategic actions of these companies reflect on the map of positioning for integrated results, like AMD.

AMD is a classical example to take co-opetition strategy between IDM and Foundry. The results of this research reveal that AMD, one of the more notable companies to have established a pure foundry company from an IDM company, is located in the foundry-oriented area. That is, AMD has prepared well to join Foundry business. We can easily detect a company's intension by the integrated map in the early stages.

(d) Some IDMs claimed to join Foundry business located in Foundry oriented area

AMD and TI positioned in the Foundry-oriented area. It implies these companies are in more competitive positions to join Foundry businesses.

(e) A positioning map of competitive analysis is provided in patent perspectives

In addition to AMD, Samsung and Intel are other companies that took action to join the Foundry business openly. The position of technology focus for these companies kept them well positioned in both wafer-process and wafer-design application technologies. The map of competitive analysis is valuable to decision makers or researchers for technology development.

6.2 Implications

During the past 30 years, the structure of the global semiconductor industry has undergone a process of progressive vertical specialization, which has resulted in the entry of specialized firms into semiconductor design, manufacture, equipment production, and most recently, process development.

The study model and findings have several important implications for organizations wishing to change their character or develop their core technology fields. One implication is that the decision makers of IDM organizations must recognize Foundry's increased power in technology level, in both the wafer process technology and wafer design application technology fields. Due to Foundry's rise to technology activity and quality, IDM/Design House should not just view it as one of their capacity providers but also should take the technology alliance with it actively. Decision makers of IDM or even Design House organizations need to take a more comprehensive strategy to deal with the shifting occurring in the industry. For example, IDM adopted the so-called Fab-Lite strategy recently to cope with increasingly expensive semiconductor equipment. However, the side effect of the Fab-Lite strategy may strengthen Foundry's financial structure and then upgrade its technology level. Foundry is expanding beyond the character of the traditional manufacturing capacity provider relying only on its affluent capital resources.

Another implication of the study's findings is the change of the mapping relationship for push-patents or pull-patents in the semiconductor industry. Traditionally, wafer design application patents and wafer process patents are regarded as the pull patent type and the push patent type, respectively. The shifting trend of the mapping relationship in Fig. 4.5 shows that wafer process patents are on the rise and becoming the pull patent type. Because Foundry's major focus, wafer process patents, has become the more lucrative patents, IDM/Design House should not view Foundry as only one of their capacity providers but should actively pursue a technology alliance with it. From the technology level point of view, we discovered that Foundry may soon compete with IDM or Design House for the technology leading position. From the research result, both IDM and Design House have nearly the same shifting trend for their major technology fields. That is, the technology filed shifting of IDM is approaching to the patterns of Design House gradually. One of the reasons for the development trend is the Fab-Lite strategy taken by IDM. To save the capital expenditure of process equipments, IDM cannot help but reduce the investment of the process equipments and R&D for process technology fields. When the character position of Foundry is on the rise, IDM, the almighty character in the semiconductor value chain for the past 30 years, will be challenged in the near future, especially on some specific technology fields. Moreover, the technology field development for Foundry is not limited to the wafer process patents but also in the wafer design application patents. What deserved to be mentioned is the down trend of the patent quality for Design House, the only character in the value chain, after 8-inch wafer size era. This development will impact the competitive energy of Design House in the long run. It may stir up the competition between IDM and Design House.

The other implication is that patents not only express company technology capability but also imply business strategies. More and more IDMs will take actions to join Foundry business by their technology activities. The results of this research reveal that AMD, one of the more notable companies to have established a pure foundry company from an IDM company, is located in the foundry-oriented area. Additionally it shows that, although Micron and TI have not officially announced their intentions to diversify or branch off as foundry companies, the two are located in the foundry-oriented area as a means of showing their competitive positions with regard to joining the foundry business.

6.3 Future Research

There exist a number of other avenues for further research into this subject. For example, IDM companies and the competitive relationship between each selected IDM and its related foundries can be studied from patent perspectives via technology forecasts. The relationships between specific technologies for each character would also be a topic for future research. Besides, future research may apply more advanced patent indicators or models to analyze the shifting of specific industries or companies. The Revealed Patent Advantage (RPA) proposed by Schmoch in 1995 was used due to the differences in R&D strategies and comp any scale of firms. In addition to the semiconductor industry, we may explore and examine the model for different industries. Meanwhile, two indicators applied to measure the inflow and outflow degree of fusion of a specific patent class belongs to cross-disciplinary technology (No & Park, 2010). For example, the technology forecast can be studied by patent perspectives for IDM companies. Besides, the research regarding to the relationship among specific technologies for each character playing will be a good topic in the future.

The main trends in U. S. patenting over the last 30 years, including a variety of original measures constructed with citation data, such as backward and forward citation lags, indices of “originality” and “generality”, and self-citations were presented (Hall et al., 2001). Three semantic similarity measurements were applied to discover un-commercialized research fronts by comparing scientific papers and patents: Jaccard coefficient, cosine similarity of term frequency-inverse document frequency vector, and cosine similarity of log-term, frequency-inverse document frequency vector (Shibata et al., 2011). Finally, both self-citations and external citations can be classified within or beyond industry citations, leading altogether to four different kinds of citations: (1) self citations within the industry, (2) self citations beyond the industry, (3) external citations within the industry, and (4) external citations beyond the industry. Novel patent analysis methods were applied to analyze technological convergence and provide tools for anticipating the early stages of convergence (Karvonen & Kässi, 2012).

This Dissertation has proposed some novel ideas to measure positing and shifting for character and technology focus. This accomplishment does not come easy and continuous effort should be invested in broadening its applicability and in solidifying its theoretical foundation.

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