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# Semiconductor industry value chain: characters' technology evolution

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## Abstract

**Purpose** – Foundry, Design House, and integrated device manufacturers (IDM) are major characters in the semiconductor industry value chain. The purpose of this paper is to discuss patterns of characters' evolution in technology through patents classified as wafer-design application patents and wafer-process patents.

**Design/methodology/approach** – Various patent indicators, such as average patent citation count, and the combination of the average patent citation count 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. The study period (1979-2009) was divided into three major technology or wafer size eras, 1979-1991 for the 6- and pre 6-inch wafer era, 1989-1999 for the 8-inch wafer era, and 1997-2009 for the 12-inch wafer era.

**Findings** – 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.

**Practical implications** – Some hypotheses are clarified to provide managerial implications for the semiconductor industry. Owing to Foundry's rise in technology activity and quality, IDM/Design House should not merely view it as one of their capacity providers but should also pursue a technology alliance with it.

**Originality/value** – The paper clarifies the traditional hypotheses of the characters of technology in the semiconductor value chain.

**Keywords** Semiconductors, Value chain, Patents, Supply chain management

**Paper type** Case study

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## 1. Introduction

This study examines the three major characters 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 integrated device manufacturers (IDM), for overall semiconductor industry integrators (like Intel, Samsung, and IBM). 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. Characters in the industry have changed in the main semiconductor industry value chain over the past 30 years (1979-2009), especially IDM. There are certainly many reasons for this change, including financial problems, manufacturing capacity, and geographical clusters (Ernst, 2005). To examine the character evolution in technology, the authors used patent analysis techniques as the quantitative basis for this study. 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). Lewison (1998) assessed the impact of funding sources on gastroenterology research in the UK using patent analysis. Huang, Z. *et al.* (2003) analyzed the longitudinal change of the international landscape of nanoscale science and engineering research and development based on information collected from the United States Patent and Trademark Office (USPTO) database. The status of research and development in high-tech electronic companies of Taiwan were explored based on their published patents (Huang, M.H. *et al.*, 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 *et al.*, 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 *et al.*, 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.

From the technology point of view, the authors attempted to apply patent activity, patent quality, and the combination of patent quality and relative patent activity share to study the evolution 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:

*H1.* IDM is a technology giant, in both technology activity and technology quality among characters in the semiconductor industry.

*H2.* Foundry excels only at wafer-process patents but is not as successful at wafer-design application patents.

*H3.* The wafer-design application patents and the wafer-process patents are regarded as the so-called "pull" and "push" patent types, respectively.

The traditional hypotheses above will be clarified through the study.

The study is organized as follows. Section 2 provides a literature review on industry development and semiconductor industry evolution. In Section 3, the authors present the research methodology. Section 4 describes the research results. Section 5 clarifies the traditional hypotheses about the characters in the semiconductor value chain. In Section 6, the authors present their discussion and suggestions for future research.

## 2. Industry development and semiconductor industry evolution

The technology evolution 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 evolution of industry structure and the development of core competences, knowledge, and skill sets within firms. In addition to the technology evolution affecting economic development, von Zedtwitz and Gassmann (2002) discussed technology evolution or development through modeling R&D internationalization with the market view. Some researchers focused on industry evolution 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. Among examinations of the characters in industry development, Patibandla and Petersen (2002) attributed the evolution of the industry in human capital accumulation to the entry of multinational corporations, 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 *et al.*, 2003). Essletzbichiler and Rigby (2005) studied the technology evolution from the perspectives of competition, variety, and geography, remedying some empirical shortcomings by exploring the spatial evolution 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. Owing 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 have been examined (Macher *et al.*, 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 information technology (IT) studies of the semiconductor by specific countries or areas. The three-level model of internet commerce adoption has been used in a survey of 287 companies and web sites in Taiwan (Peng *et al.*, 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 the studies about the evolution or relationships of the characters are focused on economics (Berger and Lester, 2009), manufacturing capacity (Lee and Hsu, 2004), and strategy management (Guilhon *et al.*, 2004). The semiconductor manufacturing industry was analyzed for different engineering collaboration mechanisms between Design House and Foundry during different stages of process technology (Guo *et al.*, 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 *et al.*, 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 *et al.* (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 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 evolution in semiconductor value chain technology during different wafer size eras and in different technology fields, especially when the character evolution 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 evolution. It may also assist researchers who are interested in exploring the semiconductor technology evolution within characters.

## 3. Methodology

The authors applied the techniques of patent analysis and used patent count, average patent citation count, and the combination of the average patent citation count and relative patent count share to stand for the activity, quality, and integrated performance of patents, respectively. The authors also examined the technology evolution by characters and wafer size eras through the patent-analysis techniques above. 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 18-24 months. By following Moore's law and reducing the transistor cost or cost per function by 30 percent 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 increasing by only 30-40 percent (which is typical), the cost per area decreases by 30-50 percent – an annualized improvement of about 4 percent when wafer size changes occur about every ten 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-, pre 6-, 8-, 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.

For data processing, 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- and back-end suppliers like tool vendors and testing/assembly houses. In addition, the authors selected dominant companies which accounted for 80 percent 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. The framework of the study is divided into three major sections: the evolution of characters, classified patents, and the combination of characters and classified patents.

### *3.1 Evolution of characters*

The character evolution of technology in the semiconductor value chain is the main focus of this study; therefore, the authors analyzed the primary patent data within technical characters to understand their evolution. 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. The authors 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, the authors also used the *post hoc* test (Scheffe) to further clarify the relationships among them.

*3.2 Evolution of wafer-design application patents and wafer-process patents*

To analyze the technology fields of each character in detail, the authors used the patents of each technology field to identify which technology field is most competitive within characters and wafer size eras. The authors targeted the patents from seven major technology fields, accounting for 75 percent 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.

*3.3 Analysis of characters by wafer-design application patents and wafer-process patents*

To obtain valuable insights into the evolution in the semiconductor industry, the authors combined the evolution of characters with classified patents. Thereby, it is expected to obtain a picture of the overall evolution 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. The authors 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 Figure 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.

## 4. Results

*4.1 Evolution of characters*

*(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 Figure 1. If its development is traced by the characters of the semiconductor industry, IDM achieved the leading position on patent count, as shown in Figure 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 Figure 2.

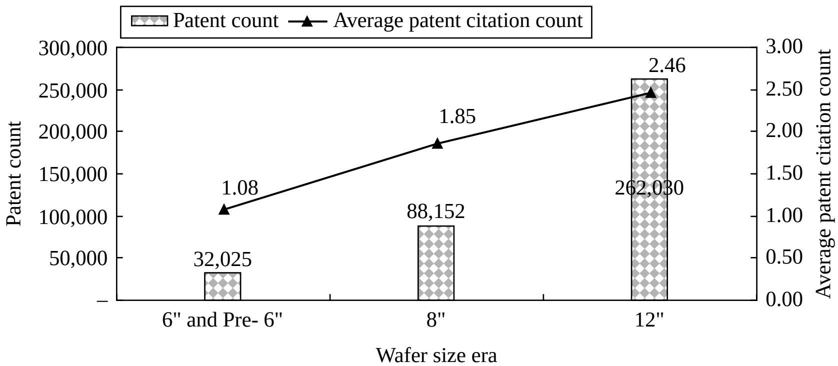


**Figure 1.**
Patent count and average patent citation count by wafer size eras

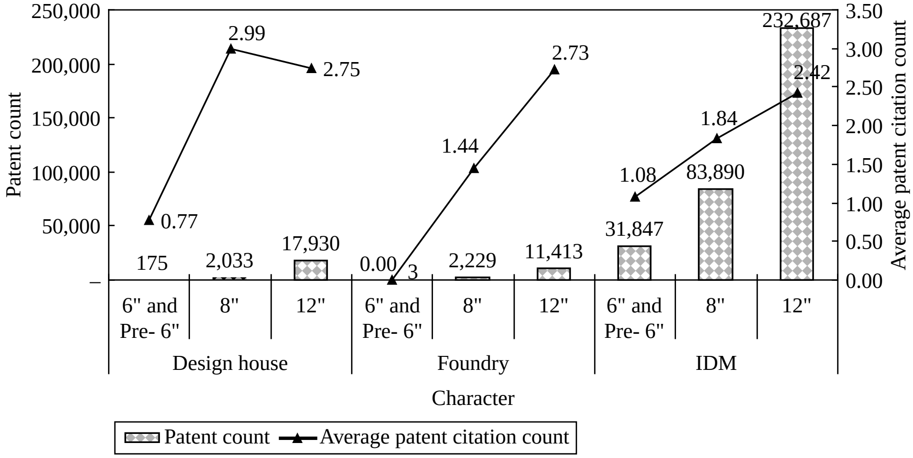


**Figure 2.**
Evolution of patent count and average patent citation count by characters

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 I. The difference in the average patent citation count of each character by wafer size era is also significant in Table II. That is, the "average patent citation count" for wafer size era or for each character – Design House, Foundry, and IDM – is statistically different.

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 II. In the average patent citation count by characters, the difference is significant for each character among wafer size eras, except in Design House's evolution from the 8-inch

**Table I.**
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 | 67,853 | 2 | 33,926.6 | 1,572.27 |
| Within groups | 8,247,218 | 382,204 | 21.6 | |
| Total | 8,315,071 | 382,206 | | |

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 evolution from the 6- and pre 6-inch wafer size era to the 8 inch.

*(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 Figure 3. It is noteworthy that IDM's "average patent citation count" measurement was below average for the 8- 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 Figure 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

| 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 | 1,053,854 | 20,096 | 52.4 | |
| | Total | 1,054,502 | 20,098 | | |
| Foundry | Between groups | 3,103 | 1 | 3,103.3 | 119.65 |
| | Within groups | 353,788 | 13,640 | 25.9 | |
| | Total | 356,891 | 13,641 | | |
| IDM | Between groups | 61,108 | 2 | 30,554.2 | 1,562.34 |
| | Within groups | 6,814,810 | 348,463 | 19.6 | |
| | Total | 6,875,919 | 348,465 | | |

**Table II.** ANOVA of average patent citation count by characters

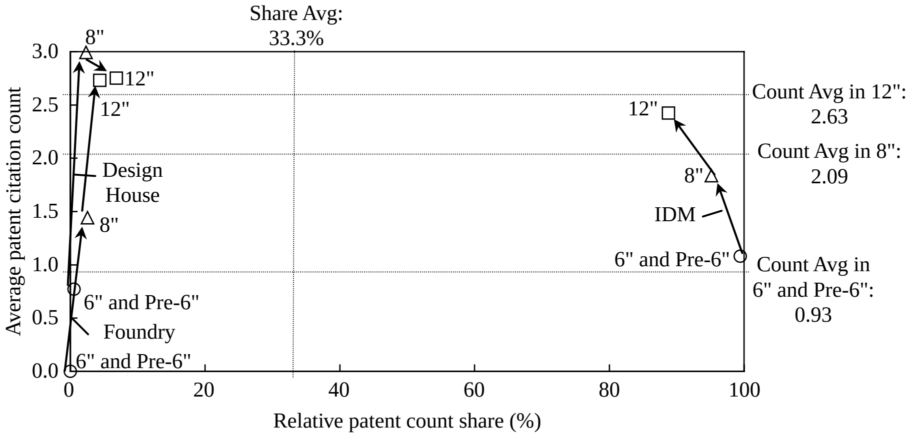


**Figure 3.** Relative patent count share vs average patent citation count by wafer size eras and characters

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. The authors discuss the insights derived from the data in great details by the following sections.

### *4.2 Evolution 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 III. 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 III. 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.

*(1) Evolution of major technology fields*. The authors continued to examine the evolution 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 Figure 4. From the evolution 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 evolution 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.

**Table III.** Summary of patent count and average patent citation count by technology fields and characters

| Category | Wafer size era (average patent citation count-overall) | Wafer-design application patent: Electronics communication | Computer software and hardware | Digital information storage | Number of competitive technology field (1) | Wafer-process patent: Chemistry | Semiconductor making or forming | Semiconductor manufacturing | Active solid-state devices | Number of competitive technology field (2) | Grand total for number of competitive technology field (1) + (2) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 percent level

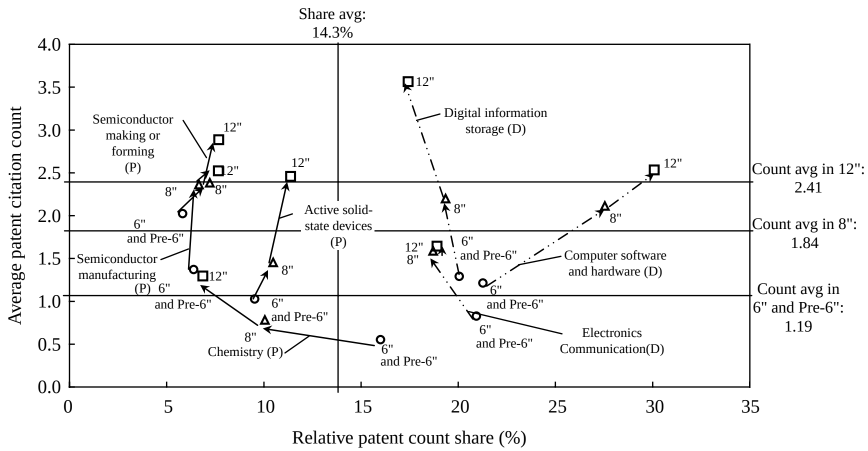


**Figure 4.**
Relative patent count share vs average patent citation count by wafer size eras and technology fields

*(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 Figure 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 evolution trend has changed in the latest 12-inch wafer size era, as shown in Figure 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 Evolution of characters and classified patents*

*(1) Design house*. The analysis of the evolution 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 Figure 5.

The technology evolution 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.

*(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 Figure 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

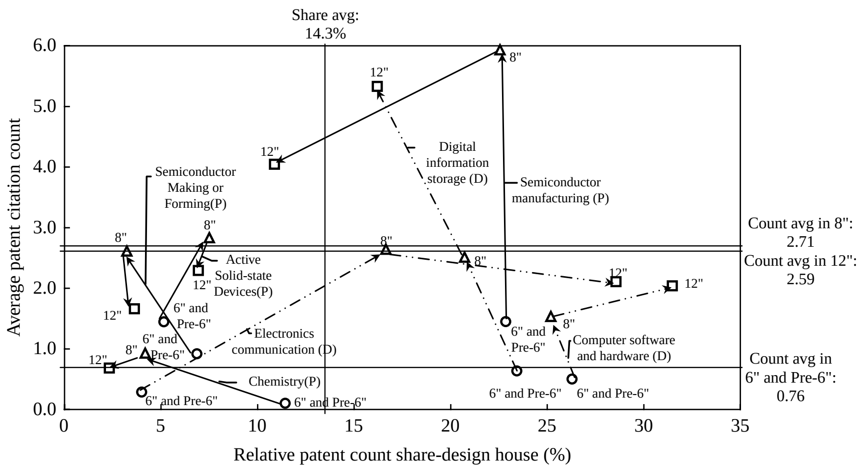


**Figure 5.**
Relative patent count share vs average patent citation count by wafer size eras and technology fields

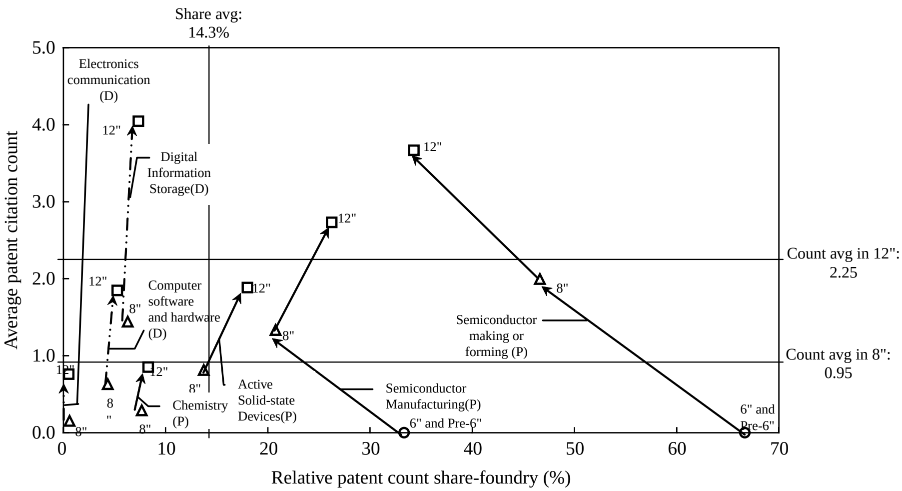


**Figure 6.**
Relative patent count share vs average patent citation count by wafer size eras and technology fields Foundry

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.

*(3) Integrated device manufacturers*. 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 Figure 7.

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

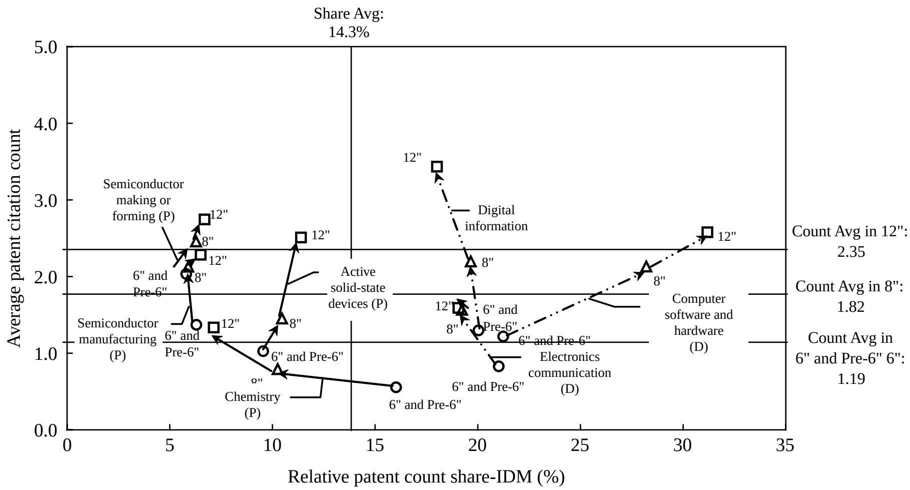


**Figure 7.**
Relative patent count share vs average patent citation count by wafer size eras and technology fields IDM

while Foundry is good at semiconductor making or forming, as shown in Table IV. Overall, IDM dominates patent activity while Design House is good at patent quality, as shown in Table IV. 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 evolution or technology evolution 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 4.2 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.

*4.4 Evolution for competitive technology fields*

The evolution 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 IV. 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 evolution trend demonstrated that it acted as not only a manufacturing capacity provider but also a technology contributor.

The authors 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

**Table IV.** Competitive technology field summary by characters and wafer size eras

| Character | Wafer size era (average patent citation count-overall) | Wafer-design application patent: Electronics communication | Computer software and hardware | Digital information storage | Number of competitive technology field (1) | Wafer-process patent: Chemistry | Semiconductor making or forming | Semiconductor manufacturing | Active solid-state devices | Number of competitive technology field (2) | Grand total for number of competitive technology field (1) + (2) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |

**Notes:** Significant at: *1 percent level; average patent citation count the 12-inch wafer size era. Foundry had the same evolution trend as Design House. IDM is its own character for concurrent evolution in wafer process and design.

In the ANOVA test result, all the data listed in the Table IV 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 IV.

*(1) Power evolution by technical characters*. To study the patent power by characters, the authors 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 V. 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 V.

*(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 percent, 43 percent, and 10 percent, respectively, in the 12-inch wafer size era, as shown in Figure 8. It is clear that Foundry's technology level has been recognized and cited by IDM and Design House significantly, with 68 percent of others-citation in the 12-inch wafer size era, as shown in Figure 8. It is also clear that over 90 percent of the patents owned by IDM are cited by themselves, as shown in Figure 8. This implies that IDM still regards itself as a 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 percent from the 6- and pre 6-inch era to the 12-inch era, showing IDM's decreasing power.

*(3) 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

| 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 |

**Notes:** Significant at: *1 percent level; cited by all/self/others

**Table V.**
Patent quality by wafer size era and characters

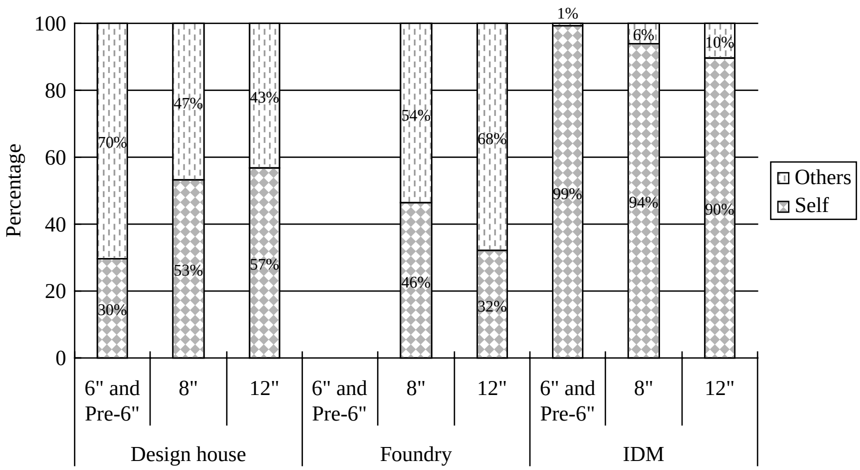


**Figure 8.**
Patent citation ratio by self/others by characters between 1979 and 2009

making or forming, and semiconductor manufacturing, respectively, as shown in Table VI. 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.

## 5. Hypotheses and clarifications

Some traditional hypotheses could be clarified from the research as follows:

*H1.* 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 evolution of the patent activity (relative count share), IDM is declining, as shown in Figure 4. As to patent quality, IDM's performance is lower than that of Foundry and

| 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 |
| | 8inch | 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** |

**Notes:** Significance at: *5 and **1 percent levels; patent quality by others

**Table VI.**
Summary for competitive Foundry technology fields by characters and wafer size eras

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:

*H2.* 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 evolution of wafer-design application patents in Foundry also performs quite well, as shown in Figure 7. The evolution 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 Figure 6. That is, Design House's technology evolution is not as healthy as Foundry's. IDM's major leading technologies are in wafer-design application patents, as shown in Figure 8, but IDM is not a powerful technology leader, based upon the study results:

*H3.* 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 Figure 5. From the patent quality perspective (average patent citation count), the wafer-process patents achieved an impressive record, as shown in Table III. All the above-mentioned data provide strong evidence that the wafer-process patents will become important or even leading characters in the near future.

## 6. Discussion and conclusion

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. Decision makers of IDM or even Design House organizations need to take a more comprehensive strategy to deal with the evolution 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 role 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- or pull-patents in the semiconductor industry. Traditionally, wafer-design application patents and wafer-process patents are regarded as the pull- and the push-patent types, respectively. The evolution trend of the mapping relationship in Figure 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, the authors discovered that Foundry may soon compete with IDM or Design House for the technology leading position.

Based on the study's results, it was found that Foundry companies are becoming technology transferors rather than merely manufacturing capacity providers. Characters in the semiconductor industry value chain have changed with different technology eras, especially for IDM and Foundry. From the technology point of view, the authors completed the patent analysis for different characters 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 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 evolution in different wafer size eras. For example, the evolution 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 Figure 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 or chief of technology officer of a company in selecting their most competitive potential patents to develop. It could also provide another perspective for academia to evaluate the character evolution trend in the industry.

Based upon the research results, both IDM and Design House have nearly the same evolution trend for their major technology fields. That is, the technology field evolution 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 Figure 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.

The limitation of the study is in the classification of each character (IDM, Foundry, or Design House). Owing to the increasing business overlap among categories in the value chain, it is difficult to identify semiconductor categories for data processing.

The authors could only refer to the industry research agencies, IC Insights and Gartner, to classify the characters of the targeted companies. Further research could address the co-opetition relationship between Foundry and IDM. It will be worthwhile to explore both technology perspectives and characters more deeply. The relationship among specific technologies for each character will also be a good topic for future research.

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