**MECN 441 S61 – Final Project**

# Is the IDM Model Doomed...

## Emergence of the Fabless-Foundry Model in the Semiconductor Industry

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# 1 Executive Summary

Until the late 1980s, manufacturers of semiconductors were vertically integrated, combining both design and manufacturing functions. The high degree of vertical integration arose due to a number of reasons. Transaction costs that were associated with the transfer of information from design to manufacturing, risks of losing intellectual property (IP) related to semiconductor design, and holdup costs associated with outsourcing manufacturing provided a powerful incentive for firms to be vertically integrated. Additionally, cost reductions arising from economies of scale in R&D and the relatively low investment requirements for manufacturing led to the rise of integrated device manufacturers (IDMs). (See Exhibit 1 for definitions of terms used in the semiconductor industry.)

The last decade has seen a shift in focus from the IDM model to a "fabless" business model (See Exhibit 2), wherein separate firms perform chip design and manufacturing functions. The rise of the fabless model may be attributed to two primary reasons. First, the emergence of new markets (communications and wireless) for semiconductors and rapidly changing technology introduced risks that necessitated the ability to fail-fast in the event that new semiconductor designs were unsuccessful. Smaller design groups are naturally able to re-deploy their intellectual assets more efficiently to cope with such market risks. This, coupled with a reduction in transaction costs associated with information transfer from design to manufacturing, increased the attractiveness of firms to specialize in semiconductor design. Second, increasing economies of scale in manufacturing arising from higher manufacturing investment requirements meant that risks associated with fluctuating market demand for semiconductors could be mitigated by aggregating demand from a number of smaller, specialized semiconductor design houses, known as "fabless" firms. This naturally led to the emergence of specialized firms, or "foundries," that concentrate solely on semiconductor manufacturing. The attractiveness of the "fabless-foundry" model was selfperpetuating in that it mitigated the risks faced by design firms of losing their IP to contract manufacturers, thereby strengthening the emergence of the fabless-foundry model. In essence, this new business model enhances the efficiency of the semiconductor industry by effectively apportioning the risk in technology and market forces to firms that are best suited to diversify and mitigate the costs of these risks.

## 2 Industry Structure circa 1990

By the end of the 1980s, the semiconductor industry had been in existence for over 30 years. As of 1990, the industry had coalesced into three main product categories – memory, logic, and micro-component products[1]. The memory market had become commoditized due to standardization, slow innovation, and excess entry. The logic and micro-component markets, which are the focus of this analysis, were oligopolistic – that is dominated by a few large, vertically integrated firms with fairly concentrated market structures in each product segment[2]. These IDMs typically performed R&D, design, manufacturing, and sales and marketing. As Mr. Chuck Byers, Director of Marketing North America for Taiwan Semiconductor Manufacturing Corporation (TSMC) and an industry veteran puts it, "Prior to the 1980s, most integrated device manufacturers had obscene levels of vertical integration (by today's standards)."

Another unique feature of this industry was its dependence on the personal computer (PC) industry. By about 1990, about two-thirds of this industry was serving the computer industry and the fortunes of the semiconductor industry were driven by the growth in the computer industry[3].

## 3 Why did the IDMs Succeed?

The IDM model, which called for vertical integration of R&D, software design, production, sales and marketing, and process equipment manufacturing, was a successful model, evidenced by the fact that nearly every company at this time was structured as an IDM[2]. In addition, the few specialized companies (in design and manufacturing) that existed in the 1980s were not nearly as successful as the IDMs (see Exhibit 3). The IDMs created value in several ways – by minimizing transaction costs involved in transferring design to manufacturing, by utilizing economies of scale in R&D, and by taking advantage of the fact that economies of scale in manufacturing were relatively unimportant at the time.

## 3.1 Transaction Costs

### *3.1.1 Intellectual Property Risks*

Due to the lack of pure-play manufacturing companies, outsourcing production meant that a company that wanted to focus exclusively on design would have to approach one of the IDMs – a potential rival. Doing this made the risks of losing their IP very high, since transferring the design specifications involved giving the rival complete access to design details. Thus the integrated model made eminent sense if a company wanted to protect rents from its work.

### *3.1.2 Communication Difficulties*

Even if this IP risk could be mitigated – through contracts, for example – the information technology and electronic design automation (EDA) tools were neither sophisticated enough nor standardized across companies to ensure data integrity during the transfer. "Firms not only designed and manufactured their own integrated circuits (ICs), they also developed proprietary EDA tools as well as proprietary manufacturing equipment," says Mr. Byers. This disparity in design tools, combined with their constant evolution, made it expensive to transmit designs across firms.

In addition, developing a working process involved a high level of interaction between the design and production teams – new production methods, experimental chips, and extensive testing and frequent reworking of masks was required[4]. Effectively, no standard cell libraries existed at that time[5]. This made production outsourcing economically impractical.

#### *3.1.3 Holdup Costs*

Apart from the prior reasons, dependence on IDMs meant taking on the risk of being denied production capacity just when the markets were doing well. "Design Houses were low men on the Totem Pole," explained Mr. Byers. "The IDMs only sold buffer capacity to these players. Problems arose due to (lack of) predictability in delivery because of the power held by IDMs, whose silicon took priority over the fabless firms."

### 3.2 High R&D Costs

Because of the relative complexity of earlier semiconductor designs and the non-existence of EDA software, large numbers of design engineers were needed to create viable semiconductor designs. This led to extremely high R&D costs. In the late 1980s the semiconductor industry was extremely R&D intensive, and most companies had high R&D/sales ratios ranging from 11% to 13%[6]. This meant that only large companies could compete in developing newer semiconductor designs.

### 3.3 Relatively Low Economies of Scale in Manufacturing

In 1972, a fully equipped high-volume IC production line required an investment of roughly $10M. By 1980, this capital cost had risen to $100M[7]. Thus, initially the costs of establishing a fabrication facility were not excessively high (see Exhibit 4). By 1989, however, the cost had risen to $400M (Intel's 80486 microprocessor)[8]. At this time, a typical fab's production volume was approximately 10,000 wafers (about 1M chips, 100 chips/wafer for most complex designs) per month. Assuming 10-year straight-line depreciation, the fixed cost was roughly equal to a little over $3 per chip[5]. In some ways, this average fixed cost is a measure of the inefficiencies from not operating at manufacturing execution system (MES). These inefficiencies can be reduced by combining the production of several companies, i.e., through outsourcing. However, given the other costs in this business and the high price (and margins) in the industry, this is a relatively minor cost and is a small price to pay for the efficiencies gained by not outsourcing production.

## 4 Changes in the Industry Structure – Emergence of the Fabless Model

The period from the late 1980s to the mid-1990s witnessed a dramatic shift in the drivers of semiconductor growth. At this time, new applications for semiconductor devices began to emerge. In 1989, almost 70% of all memory and micro-components were produced for the PC market[3]. Beginning in the early 1990s, the market for communications and multimedia devices began to grow, resulting in new opportunities for several niche semiconductor producers. This growing market was largely ignored by the larger IDMs such as Intel, IBM, and National Semiconductor. "The larger companies were not willing to invest in technologies not apparent to gain mass market status," says Jayasimha Prasad, Engineering Manager at Micrel Semiconductor, and former Technical Fellow at Tektronix. Communications and multimedia devices had begun to take the position of PCs as the key drivers of the semiconductor industry in nineties.

The emergence of the growing semiconductor market for communications and multimedia applications gave rise to smaller design houses that took advantage of these market niches (see Exhibit 5). Due to the small size of these markets and relatively high fixed cost of customized manufacturing, these new firms began as pure design houses. They did not own or operate semiconductor wafer fabrication facilities, and were therefore referred to as fabless companies. These companies designed innovative microchips, with IP rights being their main asset. These design houses collaborated with established IDMs to produce the new chips. For example, IBM, which had developed state-of-the-art process and manufacturing technologies experienced a significant decrease in its capacity utilization, causing it to become the first company to operate as a contract manufacturer of chips for the new genre of fabless companies[5].

Several factors, driven by both innovation and the maturation of the industry, allowed for the emergence of these fabless and foundry companies. First, the costs of transferring design to manufacturing dropped. Second, new technology available to the industry (EDA software) led to a reduction in R&D costs to introduce new semiconductor designs. Third, the fixed costs of fabs shot up which meant that even some large markets could no longer support dedicated manufacturing plants. Finally, the aggregation of manufacturing from several firms allowed foundries to quickly move down the experience curve.

## 4.1 Mitigation of Transaction Costs

The proliferation of the smaller design houses was limited by the same transaction costs that made the IDM model a necessity. The following section describes these transaction costs and how the emergence of the fabless model led to their mitigation.

### *4.1.1 Intellectual Property and Holdup Risks*

A natural conflict of interest between fabless firms and the IDMs occurred as they depended on the same capacity and since they were natural competitors. Moreover, the fabless companies had to allow the semiconductor firm doing their manufacturing to use and incorporate the fabless IP into their own products[9]. In addition to giving up IP rights, these firms also faced the danger of giving up most of their economic rents to the IDM capacity suppliers. The classic example of this was the relationship between Cyrix Semiconductor and IBM Microelectronics[5]. Cyrix Semiconductor, which was acquired by National Semiconductor in 1996, and then sold to Via Technologies of Taiwan in 1999, was a fabless design firm that developed microprocessors used in PCs. Prior to 1996, Cyrix had no outside foundry vendors other than IBM Microelectronics to manufacture its microprocessors. Cyrix Semiconductor entered into an agreement with IBM Microelectronics that stated that for every chip produced, IBM could keep one chip that it could use in its own PCs. In short IBM captured all of the economic rents in this arrangement with Cyrix. Events such as these created an opportunity for the profitable entry of independent (i.e. firms without IP interests) semiconductor manufacturers.

An additional problem for fabless firms was that manufacturing capacity was never assured. The needs of the Fabless companies were always subordinate to that of the IDM's they depended on. Whenever demand for IDM products increased, all production capacity would be shifted to meeting it at the expense of the fabless companies[9]. Dr. Morris Chang, then Vice President of Worldwide Semiconductor Business at Texas Instruments, saw such problems between fabless design houses and IDMs as an opportunity. He returned to Taiwan in 1984, around the time when Taiwan was launching its initiative to become a major player in the technology sector. In 1987, the Taiwanese government funded Dr. Chang's plan to develop a pure-play IC semiconductor manufacturing company – or foundry – that would enable fabless companies to take advantage of the shift in the needs of the semiconductor device market without being dependent on the IDMs. The key factors that helped bring business to the foundries even though they were less efficient initially as the IDMs were the IP and holdup risks faced by fabless firms. Since dedicated foundries mitigated these risks, they were the ideal solutions for fabless companies, particularly during the boom years. As more fabless companies were established, the foundries grew rapidly. (See Exhibit 6 for a comparison of growth in wafers production between IDMs, TSMC and other foundries over the past five years.)

Given the importance of IP protection, foundries that have built a reputation for reliability have a natural advantage over those who don't. According to Mr. Byers, "With the proliferation of fabless firms – there are about 400 fabless firms – some IDMs are increasingly transferring production to foundries, and IP protection is of utmost importance. One glitch, and foundries will lose all business.  No foundry has monopoly power over the fabless firms, especially with the advent of new foundries in Malaysia, China, and Taiwan, it is impossible to regain business."  Given the consequences of breaking this trust, it is clear that foundries must ensure that trust is inviolate in their fabless relationships. The importance of IP protection also has an affect on the concentration of the industry, since an increase in the number of competitors dilutes the incentives of protecting IP.  This ensured that the foundry industry remained concentrated – fully 70% of the foundry capacity is held by three competitors (see Exhibit 7).  (An example of how this may be played out is described in Exhibit 8.)

#### *4.1.2 Communication Difficulties*

Early on, the same communication difficulties that necessitated the IDM model also limited the growth of the fabless firm.  A significant development in the late 1980s that changed this information transfer problem was the emergence of a dominant process paradigm called the metal oxide semiconductor (MOS) manufacturing process.  This development effectively standardized the manufacturing technologies for commercial semiconductor devices.  The diffusion of MOS production technology facilitated the division of labor between device designers in fabless firms – which were now able to operate within relatively stable rules, and foundries – which were able to design their process technologies to accommodate a succession of new device designs[10]. Furthermore, as EDA tools became standardized, transferring finished designs from a fabless firm to a foundry became virtually transparent.  According to Mr. Byers, "In 1997, TSMC established a concept called the 'Virtual Fab,' which enables fabless companies to choose from a wide variety of processes available, use standard cell libraries, and send requests to TSMC to process wafers." These developments removed virtually all the communication transaction costs that existed earlier.

### 4.2 Reduction in R&D Costs

As previously mentioned, the earlier generation of semiconductors required a high level of design engineers for a given level of product complexity. This led to high costs for new microprocessor designs. However, advances in computing power, publicly available research in digital design, and the development of EDA tools soon changed this. Design tools that were initially developed by the IDMs, but were subsequently made available to the industry, are now being universally used across the industry for semiconductor design. Mr. Byers remarks, "Apart from shedding the manufacturing equipment part of the business, IDMs also shed EDA tools. Today, both of these industries are flourishing along with the semiconductor industry."

According to Milind Bedekar, former Chief Investment Strategist for Semiconductors at Prudential Securities, "Over time as the complexity of the designs increased, design tools became more sophisticated due to advances in computing technology. This allowed the design houses to become much more efficient. One person could now accomplish the tasks of an entire team. Combine this with the fact that transferring the finished designs to production became much easier and it is clear why it became easy to start a design lab with just a few talented engineers. Additionally the degree of specialization had increased tremendously." Therefore, the availability of design tools and reduction in R&D costs enabled smaller design houses to compete profitably for newer markets and designs.

### 4.3 Increase in Minimum Efficient Scale of Manufacturing

In the early days of the semiconductor industry, a small investment in manufacturing was sufficient to begin profitable production, resulting in smaller minimum efficient scale in manufacturing. Increasing complexity of semiconductor design and exceedingly exacting quality standards have necessitated a much higher investment in manufacturing capacity. From 1972 to 1990, the magnitude of investment required for a high-volume production line increased almost twenty-fold[11].

(Exhibit 9 shows the increase in fab costs over the last 30 years.) High fab costs meant that foundries, which accumulated demand for fab capacity across the industry, were in a better position than IDMs (which have product-specific fabs) to take advantage of the increase in a minimum efficient scale.

Another factor in the weakening of the IDM model was the rapid dissemination of technological know-how related to manufacturing. Advances in process technologies (the manufacture of semiconductors) have filtered from IDMs to the big three foundries (Taiwan Semiconductor Manufacturing Co., Taiwan's United Microelectronics Corp., and Singapore's Chartered Semiconductor Manufacturing Co.). This enhanced the process capabilities of wafer foundries, which quickly approached the leading edge of current industry leaders (Exhibit 10). Thus, the increase in a minimum efficient scale in manufacturing and advances in process technology served as catalysts to the growth of foundries.

### 4.4 Increased Range of Process Technology Requirements

The range of process technologies provided by foundries also ensures a unique value proposition for fabless companies that have diverse sets of process requirements. One of the driving forces behind this diversity is the need for a combination of digital and analog functions for multimedia and communications applications[12]. These specialized products require different process/ manufacturing technologies, which the foundries are better equipped to provide. As Mr. Byers of TSMC puts it, "Offering fabless companies a host of process technologies and having designers use standard cell libraries from TSMC helps to add significant switching costs for fabless firms to defect. Going to a new foundry involves requalifying the design and process."[1]

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[1] These switching costs provide an incentive for the foundries to invest in technology that by themselves may not be profitable.

This flexibility and wide range of process capabilities have drawn not just fabless companies, but traditional IDMs as well, to link with foundries. For example, Motorola is planning to outsource up to 50% of its production capacity in the next five years and Toshiba is planning to outsource up to 25% of its output in 2002-2003 to foundry partners[13]. Therefore, increased capacity requirements from both fabless firms and IDMs have fueled the growth of foundries, which, in turn, have made the necessary capital investments to upgrade their facilities with the latest technology.

### 4.5 Cost Improvements Due to Learning Effects

To a large extent, the advantages IDMs had by being ahead on the experience curve (slope of approximately 28%[14] for the typical semiconductor manufacturer) in CMOS production have been reduced. This is due to inter-generational and inter-company transfer of knowledge and the rapid accumulation of production history by the foundries (see Exhibit 11). However, as the designs are further miniaturized, new problems continue to arise due to very complicated physical phenomena – such as the quantum mechanical effect[5] – which are harder to overcome. The large foundry production capacities give them a crucial edge in overcoming these problems. In fact, given the difficulty in solving these new problems, the larger foundry capacities make it more likely that they can gain an unassailable advantage[15] than a simple analysis may suggest.

This reduction in costs from learning economies provides another incentive for fabless companies to look to foundries for their manufacturing needs. This, in turn, provides positive feedback by attracting further business, and therefore learning, from both fabless firms and IDMs.

# 5 Value Generation & Capture Under the Fabless Model

Under the IDM model, a company created value on many fronts. One was through design innovation and the aggregation of sufficient R&D capacity to reap the benefits of economies of scale. Second, IDMs created value through process innovations and by using learning economies to reduce the costs of manufacturing. In addition, IDMs created value by reducing the inefficiencies inherent in translating designs to tangible products, i.e. the problems of transferring a design to manufacturing. Finally, these large companies created value by, and were compensated for, taking on the risk of manufacturing, which at that time could not be diversified away.

## 5.1 Value Generated by the Foundries

Lately, however, advances in technology and the maturation of the industry have changed the dynamics of this value proposition. Standardization and the emergence of new tools have almost eliminated the inefficiencies of transferring design to manufacturing, thus robbing the IDM model of one of its key value propositions. In addition, the emergence of foundries has allowed the risk of holding production to be diversified, further dissipating the value created by the IDMs. It should be noted that the foundries can take on this risk without being compensated as much as the IDMs were because they are naturally diversified by virtue of serving multiple companies and multiple markets.

## 5.2 Value Generated by Fabless Companies

On the other end of the spectrum, the fabless firms focus on creating value through design innovation, thus competing directly with IDMs on this front. Previously, IDMs created value both by innovation and through economies of scale in R&D. However, as the economies gained from scale were reduced, IDMs ceased to have an advantage over the fabless firms. On the contrary, the ability of the fabless firms to take risks and move quickly into small niches gave them an advantage over the IDMs.

This problem (for IDMs) was compounded by the lowering of the barriers to entry (and exit) since huge capital investments (sunk costs) were no longer required for starting a fabless firm. In addition, the new communications markets did not have established technology standards, nor did was there a single dominant firm in the marketplace that could prevent entry by other means. The low entry and exit barriers in this industry provide firms with the option of fast exit in case of failure. This "fast-fail" approach encourages the entry of a number of firms that then attempt to create a better design (see Exhibit 12 for details). The risks of this approach are mitigated by the diversification of the investors, most often venture capitalists – who are also better at judging companies *ex ante*. Further, the fast-fail approach adds value because the probability of a "good" design increases as more companies enter the market.

### 5.3 Value Captured by the Foundries

Given the nature of the foundry side of the industry, with its large economies of scale, learning economies, and the benefits of having an established reputation for IP secrecy, it is clear that the foundries will continue to operate as oligopolies. Currently only three firms account for about 70% of the production by foundries (see Exhibit 7) and although there has been substantial entry, the major firms have a strong presence. Given the stability of the industry structure, the high barriers to entry and substantial benefits to being an early mover, it is clear that the foundries will continue to capture a large part of the rents that they create. The switching costs that the foundries are attempting to establish will also help these players garner a relatively high profit. Further, given the fragmented nature of the downstream segments, it is conceivable that the foundries could retain some of the value that is created.

### 5.4 Value Captured by the Fabless Companies

While the fabless companies do create value and the winning companies will be profitable, it is not likely that the industry as a whole will be able to extract any economic rents. The drawback of the fast-fail model is that its inherent flexibility reduces the average profits that the 'winning' firms make since it induces more entry. In other words, the fact that a company can quickly find out if it is a winner (i.e. has a good design) and exit if it does not, reduces the potential downside of entry. This, in turn, will cause more firms to enter, thereby increasing the number of eventual 'losers,' which reduces the overall profits made in the particular market. An additional cause for concern is the nature of the market where the primary customers are businesses; the contracts tend to be large and negotiated, and are therefore lumpy. Due to this feature, the rents that are captured by the 'winning' fabless companies are not the improvement over the previous design, but rather the improvement it makes over and above that made by the second-best design. This means that more entry will result in smaller profits for the winning firm and larger gains captured by the customer, for example the consumer product companies (e.g. 3Com, Palm etc.). (This situation is detailed in Exhibit 12.)

Thus, the fabless firms are in a hyper-competitive market with the winners reaping large rewards but the overall industry not reaping much benefit. This profitability is further eroded by the power that the other players, such as venture capitalists, scarce engineering talent, and foundries, hold over these companies.

# 6 Exhibits

**Exhibit 1 Definitions (As given by the Fabless Semiconductor Association – FSA)**

***Fabless*** (without a fab) refers to the business methodology of outsourcing the manufacturing of silicon wafers, which hundreds of semiconductor companies have adopted. Fabless companies focus on the design, development and marketing of their products and form alliances with silicon wafer manufacturers, or foundries.

***Foundry*** is a service organization that caters to the processing and manufacturing of silicon wafers. A pure-play foundry is a company that focuses 100% of its efforts on this service and offers no end products. These companies typically develop and own the process technology or partner with another company for it. Some companies offer 100% wafer manufacturing services and others offer foundry services to supplement their company's own requirements.

***Wafer*** is short for silicon wafer, which is a thin disk of purified crystalline semiconductor that is cut after processing into individual chips. Today's leading foundries provide 8-inch wafers, and are migrating to 12-inch wafers.

***Fab*** is short for fabrication facility or silicon wafer manufacturing plant. This term is typically used to describe an individual facility, rather than a company.

***Integrated Device Manufacturer* (IDM)** is a class of semiconductor company, which owns an internal silicon wafer fab, or, as the name indicates, the fabrication of wafers is integrated into its business. However, even IDMs may do some outsourcing.

**Exhibit 2 IDM Model vs. Fabless Model**

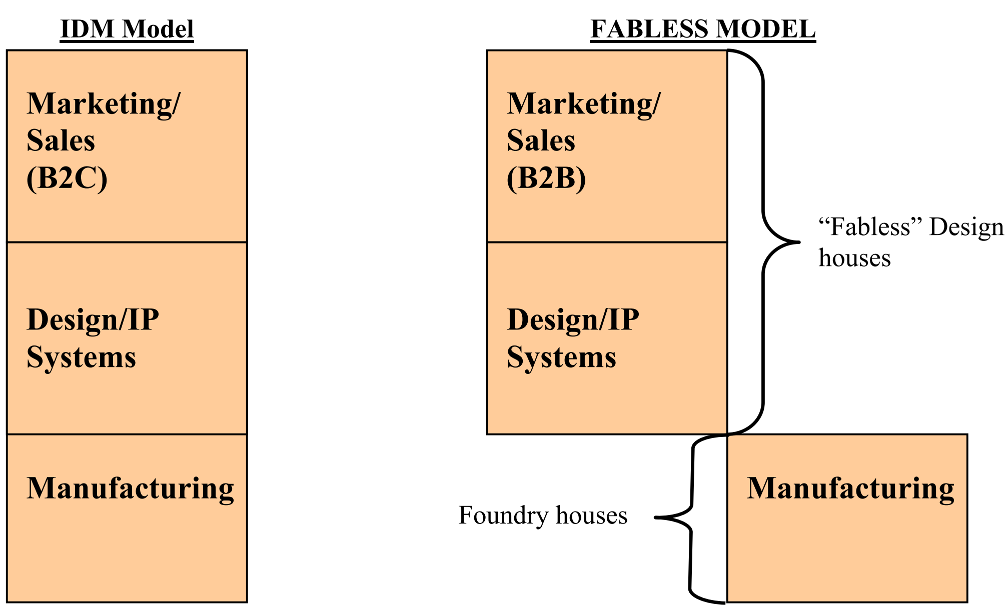
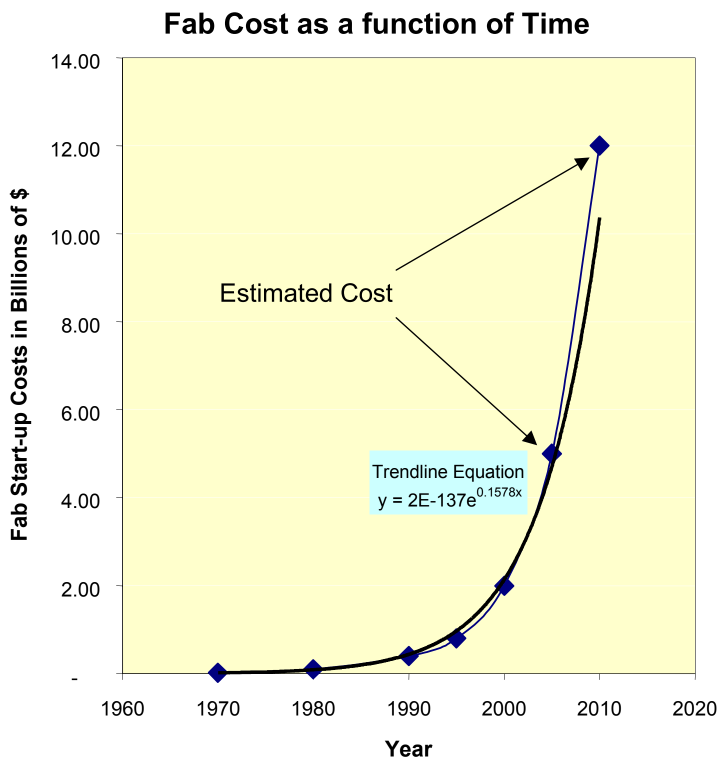


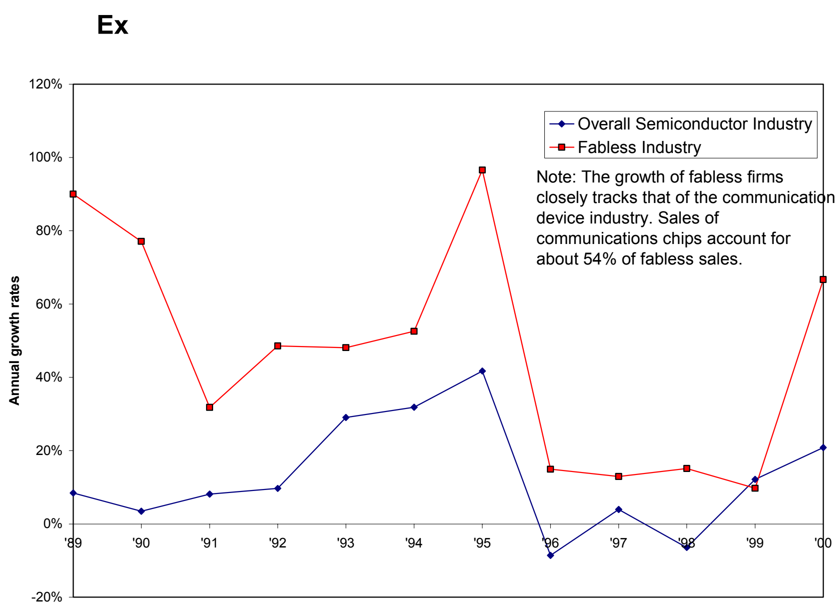
**Exhibit 3 Annual Revenues of IDMs & Foundries**

| | Annual Revenues | |
|---|---|---|
| Year | IDMs | Foundries |
| 1983 | $ 18,104 | $ 117 |
| 1984 | $ 27,701 | $ 70 |
| 1985 | $ 23,228 | $ 136 |
| 1986 | $ 29,692 | $ 207 |
| 1987 | $ 37,301 | $ 352 |
| 1988 | $ 49,837 | $ 453 |
| 1989 | $ 52,295 | $ 586 |
| 1990 | $ 53,844 | $ 753 |
| 1991 | $ 58,474 | $ 1,076 |
| 1992 | $ 63,250 | $ 1,848 |

## Exhibit 4 Increase in Fab Startup Costs Over Time




## Exhibit 5 Growth Rates of in the Semiconductor Industry




Source: The History of the Fabless Model, Jodi Shelton, Executive Director, Fabless Semiconductor Association

**Exhibit 6 Comparison of Wafer Production of Foundries vs. IDMs**

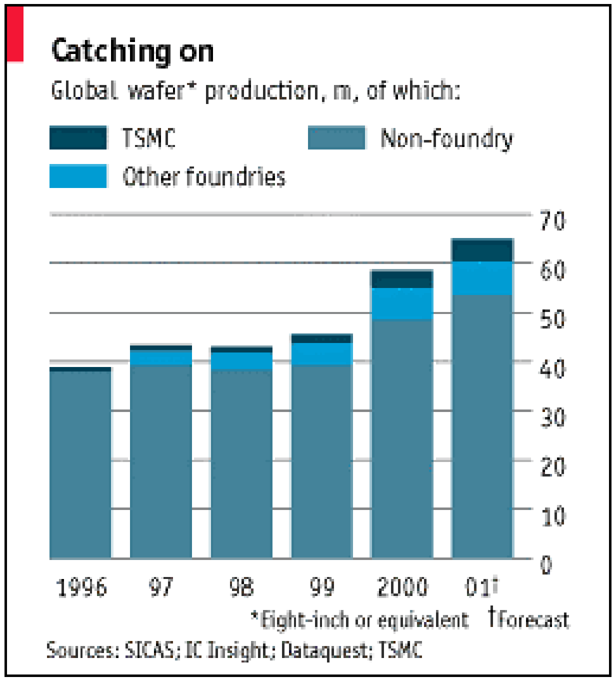
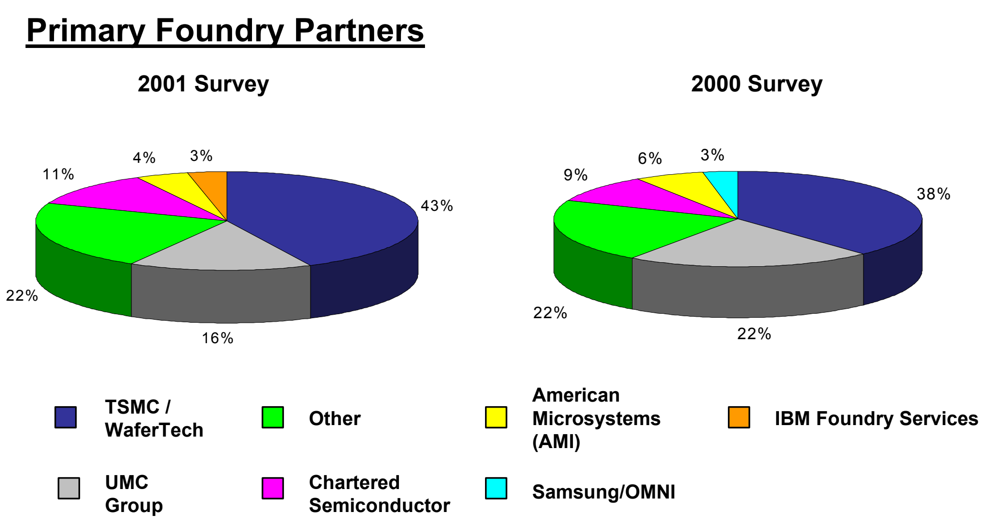



**Exhibit 7 The Foundry Industry**




Source: "History of the Fabless Model", Jodi Shelton, Fabless Semiconductor Association

**Exhibit 8 Foundry Dilemma in Protecting IP rights**

One of the key reasons that helped the emergence of the foundries was the lack of faith fabless companies had entrusting their IP to the IDMs. While IDMs could not be trusted with this information, foundries, with their dedication to be pure-play manufacturers, could be relied on to neither leak the IP to other design firms nor use it themselves.

This is because the foundries understood the importance of IP for the fabless firms and the consequences of breaking this 'code of secrecy' would be a loss of most, if not all, future outsourcing revenue. According to Mr. Byers of TSMC, "…protecting IP is of utmost importance. One glitch and foundries will lose all business." In other words, if the punishment for breaking the code is high enough the foundries will have a dominant strategy to keep the IP private.

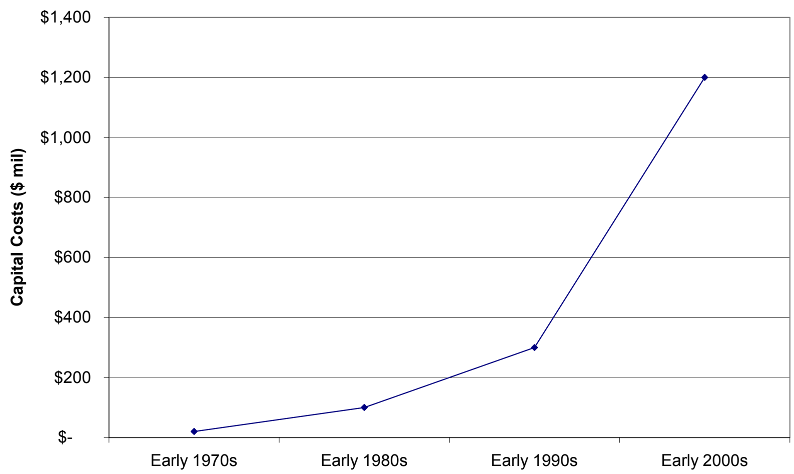
The game (payoffs to the foundry and the design firm) looks like this:

| | | Fabless firms | |
|---|---|---|---|
| | | Outsource manufacturer to this foundry | Outsource manufacturer to other foundry |
| Foundry | Keep IP secret | 100<br>10 | 0<br>8 |
| | 'Steal' IP | 500 – 600 = - 100<br>0 | 0<br>8 |

- NPV of stealing 'great' idea
- Cost of stealing idea i.e. future profits lost by breaking trust
- Net cost of stealing idea

Thus, given that the foundry has a dominant strategy to not 'steal' IP secrets, the fabless firms would rather stay with this foundry. On the other hand, without the high cost to the foundries, the fabless firms will be better off going to another foundry – even if it is less efficient (possibly due to switching costs) – since the dominant strategy of this foundry is to 'steal' the IP. In other words, the high cost of 'stealing' i.e. the certainty of losing all future business, plays an important role in protecting the IP of the fabless firms.

**Exhibit 9 Increase in Fab Costs over the Last 30 Years**




Source: US Industry in 2000, Semiconductors – J. Macher, D. Mowery, & D. Hodges, UC Berkeley.

**Exhibit 10 Advances in Process Capability of Foundries**

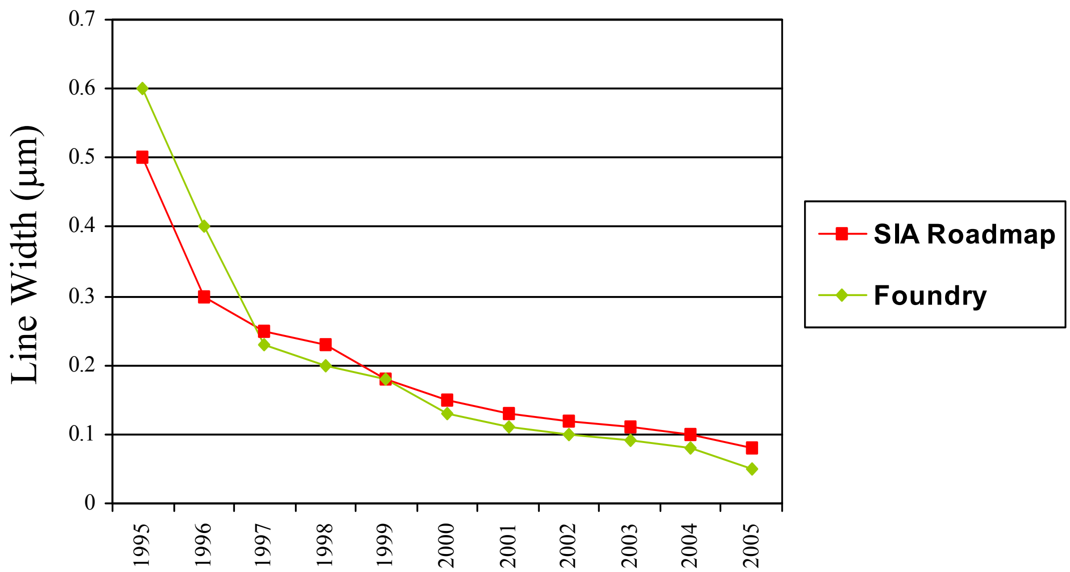
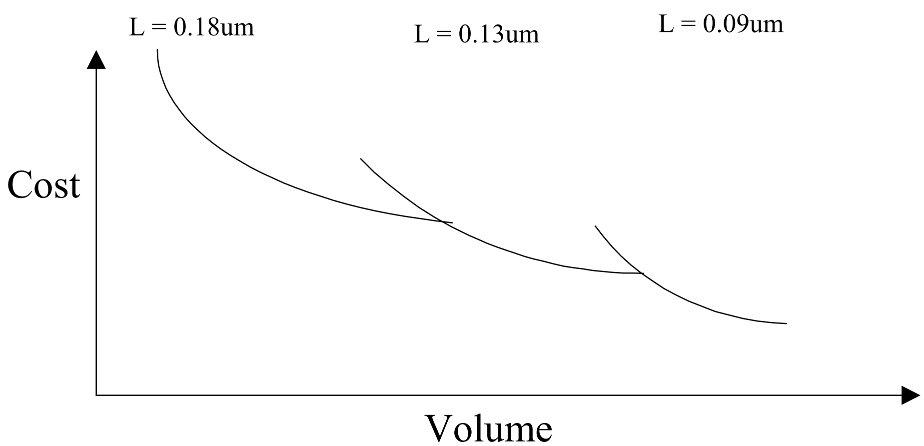


**Exhibit 11 Intergenerational Learning Curves**




Due to short life cycles, it is essential to capture learning economies as soon as possible; hence, producing high volume is essential. But often, before learning economies are obtained the price drops below the cost and firms have to switch to the next generation.

**Exhibit 12 Fast/Fail – Perfect Competition Under Uncertainty and the Value of Optionality**

As barriers to entry have come down in the semiconductor industry, it has become fairly easy for a company to gather the resources needed to stay in business. According to Milind Bedekar, former Chief Investment Strategist for Semiconductors at Prudential Securities, "…design tools became more sophisticated …(which) allowed the design houses to become much more efficient. One person could now accomplish the tasks of an entire team. Combine this with the fact that transferring the finished designs to production became much easier, and we see why it became easy to start a design lab with just a few talented engineers."

Thus, as new markets emerged, particularly in the communications industry, these companies were positioned to exploit such opportunities. Their small size and focus on speed allowed fabless firms to exploit markets as they were developing and before they were large enough to be noticed by the IDMs. Most customers in the communications market served by semiconductor companies were businesses customers. This lent a slightly different structure to competition in that fabless companies mostly competed to provide designs for other companies.

***Example:*** Consider the case where designers compete to provide the chip to Palm for use in its personal digital assistant (PDA) hand-held device. In addition to Palm, the fabless firms also compete to provide chips to Palm's competitors, such as Sony. Even though these two companies had very similar products (with the same operating system) the chip performance requirements could be different, as they need to be optimized on different dimensions – say speed versus bandwidth. As designers compete to produce the chip for the next generation of Palms, the value that they add are the design improvements over the current generation. Say that the value ($V_i$) that company i adds is either \$2, \$4, \$6, \$8, or \$10.

However, given that there are only a few winners (probably two, since Palm would like to maintain a second source for its design as a fail safe measure) the value that each designer adds is:

$V = V_i - V_{now}$ where $V_i$ is the value added by firm *i* and $V_{now}$ is the value of the current design.

However, since the value captured by a firm is only the difference between its design and the design of its next best competitor, the value captured by the 'winning' firm *n* will be:

$V_{cap} = V_n – V_j$. where j is the top 'losing' design firm. Therefore:

| | | |
|---|---|---|
| Operating $\Pi$ | $= ((V_n - V_j.) – AVC) * Volume$ | if Firm *n* 'wins' |
| | $= 0$ | If the designer 'loses' |

***Scenario 1:***

Assume that variable costs are negligible (since designers can access the economies of scale of the foundries). Also assume the fixed costs of entry are $72, that Palm needs two separate designs i.e. two firms will win, and that the volume is 50 for each firm.

In this scenario, assume three firms enter the race, so the expected value created by the top design will be 8.4, the second highest will be 6.0, and the third highest will be 3.6, (using a simulation of 5000 trials). The maximum value that Palm can capture from each 'winner' will then be 3.6 (this is Palm's BATNA given that it can capture all the value from the third design i.e. designers have no market power other than the value they create for Palm).

The *ex ante* E(Π) of a firm = ((E(Value) captured if 1$^{st}$) * Prob(1$^{st}$) +

(E(Value) captured if 2$^{nd}$) * Prob(2$^{nd}$)) * number of units

– Entry cost

= ((8.4 – 3.6) * 1/5 + ((6.0 – 3.6) * 1/5)*50 – 72

= 1.44 * 50 – 72 = $0

Since, this gives no expected profit, under this scenario the equilibrium for the industry will be the entry of three firms, two of which will win (i.e. have their designs selected).

| | | |
|---|---|---|
| Value captured by top designer | = 4.8 * 50 – 72 | = $168 |
| Value captured by 2$^{nd}$ best designer | = 2.4 * 50 – 72 | = $ 48 |
| Further, the value captured by Palm | = (8.4 – 4.8)*50 + (6.0 – 2.4)*50 | = $360 |

***Scenario 2:***

Next, consider the case when the fixed costs of entry are $59, that Palm still needs two separate designs, and that the volume is still 50 for each firm.

If four firms enter the race, the expected value created by the top design will be 8.9, the second highest will be 7.0, and the third highest will be 5.0, (again using a simulation of 5000 trials). The maximum value that Palm can capture from each 'winner' will then be 5.0 (Palm's BATNA).

The ex ante E(Π) of a firm = (3.9 * 1/5 + 2 * 1/5) * 50 – 100 = 1.18 * 50 – 59 = $0

Since, this gives no expected profit, under this scenario the equilibrium for the industry will be the entry of four firms, two of which will win (i.e. have their designs selected).

| | | |
|---|---|---|
| Value captured by top designer | = 3.9 * 50 – 59 | = $136 |
| Value captured by second best designer | = 2.0 * 50 – 59 | = $41 |
| Further, the value captured by Palm | = (5.0) * 50 + (5.0) * 50 | = $500 |

***Scenario 3:***

Now, consider the case when the fixed costs of entry are $49, that Palm still needs two separate designs, and that the volume is still 50 for each firm.

If five firms enter the race, the expected value created by the top design will be 9.2, the second highest will be 7.7, and the third highest will be 6.0, (again using a simulation of 5000 trials). The maximum value that Palm can capture from each 'winner' will thus be 6.0 (Palm's BATNA).

Thus the ex ante $E(\Pi)$ of a firm = $(3.2 * 1/5 + 1.7 * 1/5)*50 - 60 = 0.98 * 50 - 49 = \$0$

Since, this gives no expected profit, under this scenario the equilibrium for the industry will be the entry of four firms, two of which will win (i.e. have their designs selected).

| | | |
|---|---|---|
| Value captured by top designer | = 3.2 * 50 – 49 | = $111 |
| Value captured by second best designer | = 1.7 * 50 – 49 | = $36 |
| Further, the value captured by Palm | = 6 * 50 + 6 * 50 | = $600 |

***Conclusions***

Thus, as the fixed cost of entering the race decreases, the number of entrants increase. While the net expected value of all the entrants is zero in all cases, the total value created increases. However, as the number of entrants increases, the value captured by the 'winners' actually decreases and the value captured by Palm increases.

**Exhibit 13 List of Industry Experts Interviewed**

| | |
|---|---|
| Chuck Byers: | Director of Marketing North America, Taiwan Semiconductor Manufacturing Corporation (TSMC), and a veteran of the industry |
| Milind Bedekar: | Former Chief Investment Strategist for Semiconductors at Prudential Securities |
| Jodi Shelton | Executive Director, Fabless Semiconductor Association |
| Lisa Newton: | Membership Manager, Fabless Semiconductor Association |
| Sagar Pushpala: | Director, Waferfab Operations, Maxim Integrated Products |
| Kulwant Egan: | Director, Foundry Relations, National Semiconductor Corporation |
| Sandeep Deshpande: | Equity Research Analyst for Semiconductor Foundries, Dressner Kleinwert Wasserstein, Hong Kong |
| Weidong Chen: | Engineering Manager, Intel Corporation |
| Jayasimha Prasad: | Engineering Manager, Micrel Semiconductor, and former Technical Fellow at Tektronix Communication |
| Manoj Roge, | Marketing Manager at Cypress Semiconductor |
| Christopher Keil: | Director, Business Development, Vennworks (VC Firm). Chris Keil is also an industry veteran. |

Authors would like to thank all the people involved in the discussion for providing valuable insights and/or providing industry data.

## Exhibit 14 : Bibiliography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