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OF DOMINANT DESIGNS, FIRM STRATEGIES AND COMPETITIVE ADVANTAGE: EXPLAINING THE "RESURGENCE" OF THE U.S. IN THE SEMICONDUCTOR INDUSTRY

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ALLAN AFUAH
UNIVERSITY OF MICHIGAN BUSINESS SCHOOL

Of dominant designs, firm strategies and competitive advantage: Explaining the "resurgence" of the U.S. in the semiconductor industry*

Allan Afuah

University of Michigan Business School, 701 Tappan
Ann Arbor, Michigan 48109-1234, USA
e-mail: afuah@umich.edu, Phone: (313) 763 3740. FAX (313) 936 0282

Abstract:

Explanations for why the United States lost its leadership position in the semiconductor industry have focused on the national level, attributing the loss to such variables as a lack of savings, little long-term perspective, high cost of capital, and poor government policies. These explanations do not fully explain why many American firms have continued to perform well, or why since 1991, the U.S. has been making a comeback. This paper focuses on the firm/product level and suggests that although conditions in the U.S. were not conducive to post-dominant design activities, strategic actions taken by many firms to protect their entrepreneurial rents not only enabled them to overcome these conditions, they also enabled them to change that environment. The paper explores the strategies of three firms—Intel, Micron Technology, and Texas Instruments—during the evolution of nine products and suggests that the type of product technology in question *and* firm strategies for protecting their entrepreneurial rents had both a direct and indirect effect on their success. Directly, the strategies allowed the firms to overcome an environment that hampered post-dominant design success. Indirectly, they influenced the local environment which, in turn, impacted firm success. [**Key phrases: Dominant design, protecting entrepreneurial rent, semiconductors, strategy**]

1. Introduction

In the 1980s, the United States market share of worldwide semiconductors started to decline. Several explanations were advanced to explain the trend. For example, Dertousos, Lester, and Solow (1988) attributed this decline to outdated strategies, short term horizons, technological weaknesses in development and production, neglect of human resources, and the failure of cooperation between government and industry. Borrus (1988) and Ferguson (1989) attributed the decline to industry structure: Japanese semiconductor firms were vertically integrated diversified

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firms that were cross-subsidized by downstream businesses, whereas American merchant semiconductor makers had arms-length customer and supplier relations. Others blamed it on the high cost of capital, unfavorable exchange rates, and government policies in the U.S. These explanations fall short of explaining why firms such as Intel, Micron Technology, LSI Logic, Motorola, and others have continued to perform well. They also do not fully interpret why, in the early 1990s, the U.S. staged a comeback, reclaiming its leading position.

This paper argues that an exploration of the causes of the decline in the U.S. lead in the semiconductor industry and its subsequent resurgence may be incomplete without a firm/product level perspective. Such a perspective provides more insights into how a firm can react to its local environment, influence the environment or make profits in spite of it. The paper explores the strategies of three firms—Intel, Micron Technology, and Texas Instruments (TI)—during the evolution of nine products that in 1995 accounted for more than $50 billion in sales. Each firm pursued some combination of three types of strategies for protecting entrepreneurial rents: (1) collaborative *(team-up)* in which a firm allies with others to, for example, improve its chances of gaining a standard or dominant design; (2) *block* in which the firm prevents others from imitating its innovation; and (3) *run* in which the firm frequently introduces new products and cannibalizes its own products before anyone else (Afuah, 1995). Intel, for example, licensed its microprocessor design early in the product's life cycle. When its architecture emerged as the standard microprocessor for personal computers, it refused to license it to anyone or renew existing licenses and vigorously defended its copyrights and patents to prevent entry. At the same time, Intel also introduced new products more rapidly, cannibalizing existing products and leaving the competition behind while building brand recognition through its *Intel Inside* campaign to further build barriers to entry. Micron Technology, Motorola and TI followed somewhat similar strategies.

The strategies pursued by each firm in protecting its entrepreneurial rent had both a direct and indirect effect on its success and that of the U.S. semiconductor industry. Directly, the strategies allowed each firm to remain competitive. Indirectly, they allowed each firm to influence its own proximate environment which, in turn, had an impact on national industry competitiveness. It was not a single decision by a single firm that staged the U.S. comeback.

The paper is organized as follows. For motivation, Section 2 uses the evolution of DRAMs to illustrate an earlier trend in which a U.S. firm would invent and commercialize a semiconductor product but, shortly after the emergence of the dominant design, the firm would lose its competitive advantage. Section 3 presents a framework and strategies for exploring why some U.S. firms stayed competitive and helped the U.S. stage a comeback in the semiconductor industry. Section 4 explores the strategies that Intel, Micron Technology, and TI have used to not only prosper in the industry, but also impact their proximate environment and ultimately the U.S. semiconductor industry. Section 5 is the conclusion.

Product	Inventor	Introduced	1994 Sales ($US million)	U.S. 1994 (%)	Japan 1994 (%)	Europe 1994 (%)	ROW 1994 (%)
SRAM	Intel (USA)	1969	4,110	25	62	3	10
DRAM	AMS (USA) Intel (USA)	1971	23,050	15	54	3	28
Microprocessor	Intel (USA)	1972	24,080	66	29	3	2
EPROM	Intel (USA)	1971	1,410	34	29	23	14
E^2PROM	Xicor. Seeq	1983	500	51	12	24	13
Gate Arrays	LSI(USA)	1980	5,200	38	38	15	9
ROMs	IBM (USA)	1970a	2,075	15	72	2	11

Table 1: Major Semiconductor product innovations. Source for 1994 Sales estimates: Integrated Circuit Engineering of Scottsdale, AZ (ICE, 1995).

2. The trend

U.S. firms invented most of the semiconductor products whose sales have grown to $91 billion in 1994 (ICE, 1995). Some of the most popular of these products—DRAMs (Dynamic Random Access Memories), SRAMs (Static Random Access Memories), EPROMs (Electrically Erasable Read Only Memories), E^2PROMs (Electrically Erasable Programmable Read Only Memories), ROMs (Read Only Memories), Microprocessors, Gate Arrays, and Flash Memories—

are shown in Table 1. Below and in the Appendix, the evolution of some of these products is explored.

2.1 DRAMs

The DRAM is the gut of the computer and other logic systems—it is used as the main memory where programs are normally stored during execution. When Personal Computer (PC) manufacturers describe a system as having 4 Megabytes of memory, they are usually referring to the amount of DRAM. In some computer products like workstations, DRAMs actually cost more than the microprocessor, the brain of the computer. Over $23 billion worth of DRAMs were sold in 1994 alone (ICE, 1995).

Each bit of information in the DRAM is stored as an electrical charge in a capacitor. Since this charge decays rapidly, every millionths of a second or so, the capacitors have to be recharged (or refreshed, in the parlance of the industry).[1] When Intel introduced the first DRAM in 1970, the device had three transistors per bit of information and was labeled a 3-transistor cell device.[2] The original chip contained only 1024 bits of information, compared to today's chips that have 64 million bits. It also required several power sources, one to refresh the memory and the others to supply the power for moving the data. Subsequently, many firms entered the DRAM market and together with pioneer Intel, they made several key product innovation contributions. First, Intel developed a one-transistor cell. This was an important innovation since the fewer the number of transistors required to store a bit of information, the more such bits chipmakers could pack on a chip. The next two innovations were made by Mostek. First, it reduced the number of power sources needed for the DRAM to one; and introduced an innovation called *multiplexed addressing*.[3] Both the one power supply innovation and multiplexed addressing were introduced

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[1] It is the fact that the product has to be refreshed every so often that gives it the name "dynamic".

[2] Advanced Memory Systems is normally credited with the first design of a DRAM. It did not, however, have the process technology to build a commercially viable chip, Intel did.

[3] To read or store information in a RAM, the computer must send it an address signal through the pins that normally stick out of the chip. The way the address pins of the first DRAMs were designed was such that the number of pins grew rapidly as the bit density of the chip increased. Mostek's *multiplexed addressing* allows the DRAM to have considerably fewer address pins as the density increases.

with later versions of the 4K DRAM, and in going to the 16K DRAM, the dominant designed had emerged.[4] Since then, there have been certain critical features that DRAM designers have not had to rethink each time they are introducing new DRAM models, from that 16K to today's 64M. These features include a one-transistor cell, a refresh mechanism that recharges the capacitor of the cell, one voltage source, and multiplexed addressing.

The emergence of the dominant design shifted the emphasis to process innovation. Thus, the 64K required, among other things, design for manufacturability and manufacturing competences such as better use of equipment from suppliers. Process innovations required closer working relations with suppliers of such equipment as automatic testers, photolithography machines, and other process equipment like ion implanters and plasma etchers. As newer generations of DRAMs were introduced—256k, 1M, 4M—U.S. firms dropped out as Japanese firms took over the once U.S.-dominated DRAM business. Intel exited the market in 1984. Others followed including Mostek, the firm that had been responsible for so much of the dominant design. At one point only two U.S. firms remained in the DRAM business: Micron Technology—a start-up of entrepreneurs from Mostek—and veteran TI whose strategies for staying competitive in the market are explored later.

This case of the DRAM in which a U.S. firm invents a semiconductor product but loses its competitive advantage following the emergence of a dominant design, is not unique. As detailed in the Appendix, this was a trend and the subject of much debate in the late 1980s. Most of the debate suggested that U.S. local conditions were conducive to pre-dominant design activities but not post-dominant ones—that the conditions in the U.S. were not conducive to manufacturing. The debate has now taken a new turn given the resurgence of the U.S.

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[4]Utterback and Abernathy (1975) developed the concept of "dominant design". This is a design whose major components and underlying core concepts do not vary substantially from one product model to the other, and the design commands a high percentage of the market share. See also Utterback (1994), Anderson and Tushman (1990), Clark (1985), and Henderson and Clark (1990).

3. Framework

Asking why a nation's firms would lose their leadership position in an industry and/or regain it is tantamount to asking the question: How do firms protect their entrepreneurial rents with the help of their national environment? Figure 1 provides a framework for exploring this question. A firm can continue to make profits if it keeps offering products/services at a lower cost than its competitors and/or keeps offering differentiated products at premium prices that more than compensate for the extra cost of differentiation (Porter, 1991). Four factors allow a firm to do so: (1) the firm's strategies for protecting its entrepreneurial rents; (2) the competences and endowments that underpin the firm's ability to offer low cost or differentiated products; (3) its national environment; and (4) the nature of the technology that underpins the products.

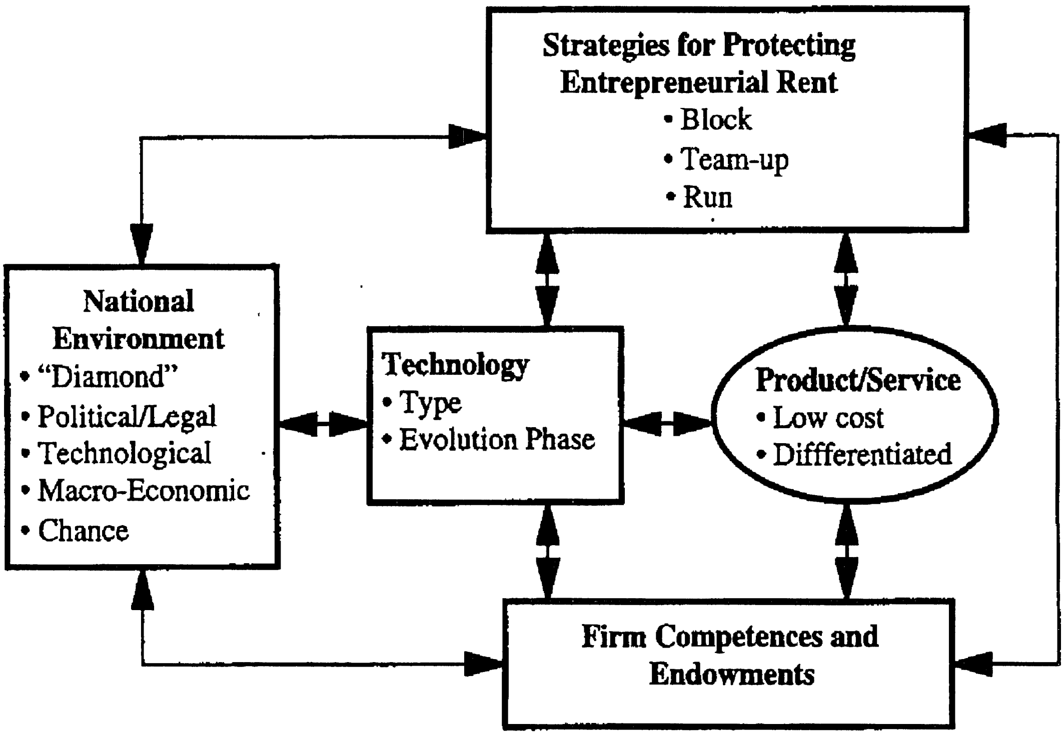

Figure 1: Role of a nation and its firms in protecting entrepreneurial rents.

3.1 Strategies for protecting entrepreneurial rents

Profits from an innovation are likely to attract competitors and the innovator must find ways to protect them. Three generic strategies have been proposed: (1) *block* in which the firm prevents others from imitating its innovation; (2) *team-up* in which a firm allies with others; and (3) *run* in which the firm frequently introduces new products to stay ahead, sometimes cannibalizing its own products before someone else does (Afuah, 1995). A firm can *block* in two ways. First, if its capabilities at each stage of the value chain are unique and non-imitable, the firm can limit their access thereby keeping out competitors. That would be the case, for example, when the firm has intellectual property that is protectable (Teece, 1986). Secondly, if all firms are equally capable of performing these activities, incumbents may still prevent entry by signaling that post-entry prices will be low (Tirole, 1988). This is achieved, for example, by establishing a reputation for retaliating against new entrants or by making heavy nonreversible investments (Ghemawat, 1991). Such signals can prevent profit-motivated potential entrants from entry.

Blocking works only as long as a company's competences and endowments are unique and inimitable or as long as industry barriers to entry last. But competitors can circumvent patents or copyrights and challenge them in court until they fall. Moreover, such capabilities last only until discontinuities such as deregulation/regulation, changing customer preferences and expectations, and radical technological change render them obsolete.

The *run* strategy admits that blockades to entry, no matter how formidable they may appear, are often penetrable and/or eventually fall. Sitting behind these blockades only gives competitors time to catch up or leapfrog the innovator. The innovator must *run*. That is, it must be innovative enough to build new capabilities and introduce new products rapidly, well ahead of its competitors. It must be able to obsolete its own capabilities and/or cannibalize its products before competitors do. *Running* can give a firm many first-movers advantages including the ability to control parts of its own environment.

The *Team-up* strategy is almost the opposite of *block*. The incumbent actually encourages entry. The question is: Why would a firm want to give away its technology? Five reasons have been suggested: to win a standard (dominant design); to increase downstream demand; to build capabilities; to exploit the second source effect; and to access markets that would otherwise be inaccessible (Harhoff, 1991; Garud and Kumaraswamy, 1993; Hariharan and Prahalad, 1994). *Teaming-up* can also be with a government.

These three strategies for protecting entrepreneurial rents are a function of the other three building blocks of Figure 1: national environment; type of technology; and firm competences and endowments. A firm can use the appropriability of its intellectual property to prevent entry only if its nation's legal system allows that, and if the firm has the intellectual property and the ability to defend it. It also depends on how tight the appropriability of the technology is. *Team-up* is also a function of the nation's political/legal system and the firm's competences. It is also a function of the type of technology and where the product is in its life cycle.

3.2 *Competences and endowments*

A firm's competences are its ability to perform the activities that underlie the offering of low cost or differentiated products/services to customers. These abilities can be in anything from designing high-performance automotive engines to finding attractive markets and locating the right products in the right positions in these markets (Wenerfelt, 1984; Cool and Schendel, 1988; Prahalad and Hamel, 1990; Barney, 1991; Rumelt, 1991; Teece, Pisano, and Shuen, 1992; Burgelman, 1994). Endowments are things like brand name, patents, reputation, geographic location, client relations, and distribution channels that allow a firm to leverage its competences. The ability of a firm to implement its rent-protecting strategies, offer low cost or differentiated products, or influence its proximate environment, rests on its competences and endowments. Thus, a firm can introduce new products faster than its competitors only if it has the capabilities to do so or can acquire them rapidly. It is also easier for a firm to find alliance partners if it has competences or endowments that complement a potential partner's. Firms that have good relationships with their government are more likely to influence legislation in their favor than those that do not.

3.3 National environment

According to Porter (1990), four characteristics of a firm's local environment are instrumental to the firm's competitiveness: factor conditions; demand conditions; related and supporting industries; and firm strategy, structure, and rivalry. These, together with political/legal conditions, and technological and macroeconomic conditions can have a profound impact on a firm's ability to protect its entrepreneurial rents as well as the competences and endowments that the firm can build. National environment has both a direct and indirect impact on local firms' ability to protect their rents from innovation. Directly, for example, enactment and enforcement of laws to protect copyrights, patents, and trade secret can play a critical role in the appropriability of local inventions. Cooperation among firms is also a function of local policies. For example, until the mid-1980s, U.S. anti-trust laws did not allow certain R&D cooperations. This changed after many firms lobbied, making the formation of such alliances as Sematech possible.

Indirectly, a firm's environment influences its competences and endowments. For example, U.S. firms must prove that the drugs they want to market are not only safe, but also possess therapeutic value—that is, the drugs actually cure the ailment for which they are earmarked. Successsful U.S. firms build competences that allow them to be better global competitors (Thomas, 1989).

3.4 Technology

The technology that underpins an innovation also plays a key role in the ability of a firm to protect its profits from the innovation. Two things affect this ability: the type of technology and the evolutionary phase. Some technologies are more difficult to imitate than others. For example, software such as operating systems is more protectable because it is copyrightable than memory chips whose patents are easily circumvented. Winning a product standard is more important for products that exhibit network externalities. Firms may want to form alliances in such cases to improve their chances of winning the standard (Hariharan and Prahalad, 1994).

As a technology evolves, the type of environment that it takes to profit from it also evolves. In particular, the type of environment that supports pre-dominant design activities is different from that required to support the post-dominant design (Utterback and Afuah, 1995). Prior to the arrival of a dominant design, emphasis is on product innovation (Utterback, 1994). This favors a region whose research institutions emphasize product R&D, where demand conditions emphasize product features, and which has a significant number of lead users. The presence of industries that provide design tools and services, as well as a broad scope of complementary products, can also nurture product innovation. Finally, access to technological knowledge, availability of venture capital funds, and free movement of employees between firms, allows many firms to be started that capitalize on new product ideas from incumbents or universities.

Following the emergence of a dominant design, emphasis shifts to process innovation and incremental product innovation—manufacturing. Demand conditions that emphasize low cost, and large number of customers who tend to be followers, also favor the post-dominant design era. The presence of suppliers of special materials and equipment needed for the increased emphasis on process innovation can also be valuable.

Thus an environment that is conducive to pre-dominant design firm performance may not be for post-dominant design, and a firm whose environment is conducive to product innovation may find itself performing well early in the life of a product and poorly once a dominant design has emerged.

As this framework suggests, it takes more than national environment to protect a firm's or nation's entrepreneurial rents. The following cases of Intel, Micron Technology, and TI show how a firm can, directly or indirectly, protect its entrepreneurial rents and help improve the competitiveness of other firms in its proximate environment.

4. The cases of Intel, Micron Technology, and Texas Instruments.

The strategies pursued by the firms have allowed them to perform well, and have actually influenced the proximate conditions that have returned the U.S. to the top of the semiconductor industry.

4.1 *Intel*

Intel's success and, to some extent, the U.S.'s success in the semiconductor industry can be attributed to a series of strategic decisions that the firm has been taking since it invented the microprocessor.[5] It has erected and defended blockades to entry by vigorously protecting its intellectual property (copyright, trademark, patents, and trade secret), accelerated the rate at which it introduces new generations of its microprocessors (self-cannibalization), and advertised to increase its brand name recognition.

4.1.1 Early alliances

In the mid 1970s, Intel licensed out its 1972 invention—the microprocessor—to several semiconductor and computer companies including Mostek, AMD, and NEC. Together, these firms built an alliance that assured customers of future supplies of microprocessors and of the systems support that is a vital part of designing a microprocessor architecture into a new system. Together, they also developed the many complementary chips that are critical to the success of a microprocessor. In 1980, when IBM needed a microprocessor for its personal computer, it chose

[5]Intel's success has been attributed to its decision to get out of the DRAM business and concentrate on the microprocessor. While the firm's focus on microprocessors may have helped its generic rent-protecting strategies, it was not, in and of itself, enough to give the firm the dominant and near monopoly position that it now holds in microprocessors for personal computers. It has also been suggested that it was an infusion of $400 million from IBM (through an equity stake that IBM acquired in Intel) that made the firm's success possible (*The Economist*, 1995a). Such an infusion from DEC to MIPS did not save the pioneer RISC microprocessor maker. If a single incident had to be chosen as the key point in the firm's history, it would either be IBM's choice of the Intel microprocessor architecture for its PC or the landmark ruling by judges Ingram and Gray that microcode is copyrightable.

Intel's, partly because of the availability of these many complementary chips at low prices, thanks to the alliances the firm had forged.[6]

4.1.2 Protecting intellectual property

As the Intel architecture emerged as the dominant design in microprocessors, Intel decided to keep newer versions of the chip proprietary, prosecuting any firm that violated its intellectual property. In keeping with this decision, it filed a suit against NEC claiming that NEC had violated the copyright on the microcode[7] for its 8088 and 8086 microprocessors. In 1986, Judge Ingram ruled that NEC had violated Intel's 8088 and 8086 microcode copyright. Until then, it was not clear if microcode was copyrightable or not. Software was copyrightable but hardware was not. And since microcode is somewhere in the middle of the two, it was for the courts to decide. This was a landmark case—the decision that microcode was copyrightable. NEC appealed the case because Judge Ingram belonged to an investment club that owned $80 worth of Intel stock in his name. When the case was retried in 1989, Judge William Gray ruled again that NEC had violated Intel's 8088 and 8086 microcode. That is, microcode is copyrightable. The ruling meant that the microcode for the next generations of Intel microprocessors was copyrightable and therefore the firms to which Intel had licensed earlier versions of its microprocessors could not build later generations of its microprocessors without new licenses. Intel was not about to give anyone any new licenses.

Fighting NEC in court sent a message to the microchip community that Intel would use legal means to protect its intellectual property. Intel made this threat even more credible when it filed a lawsuit against AMD and subsequently won. Table 2 highlights Intel's legal fights to protect its intellectual property.

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[6]One reason often given for IBM choosing the Intel design is the fact that Intel had a version of its 16-bit design (the 8088) that could use the older and cheaper 8-bit complementary chips. Since IBM wanted a low cost PC, it chose Intel's 8088.

[7]This is a layer of instructions that helps execute instructions from a computer's instruction set. It is a bunch of 'ones' and 'zeros' imbedded in the microprocessor's hardware.

Year	Event
1981	IBM elects to use Intel's microprocessor in all its personal computers.
1982	Intel files a law suit against NEC alleging violation of its microcode copyright on the 8088 and 8086.
1983	Fight between NEC and Intel is settled in a secret agreement.
1984	Relations between Intel and NEC flay up again. Intel goes back to court.
1986	Judge William Ingram rules that microcode is copyrightable.
1989	Case comes back to court and Judge Gray rules that Intel's microcode for its 8086 and 8088 are protectable under U.S. laws. Effectively, chip makers can copyright microcode.
1990	Filed a suit against AMD alleging violation of its trade mark when AMD use the numbers 386 in the naming of its part AM386
1991	Intel files a law suit against AMD claiming two things: That AMD had violated the copyright for its 386 microcode as well as the control program in 386's PLA.

Table 2: Chronology of Intel's legal fight to protect its intellectual property.

Despite Intel's success in defending its intellectual property, some firms entered the Intel microprocessor architecture market. AMD, Cyrix, NextGen, IBM, and Chips & Technologies at one time or the other, produced Intel-compatible microprocessors. Consequently, in addition to protecting its intellectual property, Intel had to seek other ways to protect its profits from these entrants. In 1985 it got out of the DRAM business to concentrate on microprocessors (Burgelman, 1994). With the focus on microprocessors, the firm was able to develop new generations of microprocessors with dramatically higher complexity (as measured by the number of transistors in each chip) and mind-numbing increase in performance (as measured by the number of instructions that the microprocessor executes per second[8]). What is of more significance is that Intel was able to introduce these more complex and better-performing processors at a faster rate than it had the slimmer and slower earlier generations (see Table 3). For example, the P6 (Pentium Pro) will be introduced only three years after the Pentium and should be about twice as complex and twice as fast. This compares favorably with the 486 that was introduced four years after its predecessor, the

[8] This is usually measured using MIPS (Million Instructions Per Second), a unit of performance that one design manager and former colleague of the author jokingly called "Meaningless Indicator of Performance".

386. Some generations of microprocessors were introduced before sales of the earlier generation had peaked (see Table 3).

Intel has also been working hard to establish a brand name identity. Although the microprocessor has been responsible for most of the performance improvements in personal computers, this processor has been buried in the black box that is the personal computer, and with it, Intel's identity. That is until 1991 when Intel went directly to end-users, advertising heavily and promoting its *Intel Inside* logo in numerous technical and business magazines, and on national television. It also promoted its logo by offering PC makers discounts on chips if they displayed the logo on the PCs they sold.

Another thing that Intel has going for it is the high cost of a semiconductor plant, which at $1.5 billion,[9] now constitutes a barrier to entry for many firms. The fact that Intel has already built these plants, has concentrated on microprocessors ever since dropping out of memory chips in the 1980s, and the fact that it has a war chest[10] of about $10 billion dollars, sends a signal to potential entrants that any entry attempts will be fought.

Processor	Description	Number of Transistors	Design Start	Formal Introduction	Volume Shipments	Peak Sales	Initial Speed (MIPS**)
286***	16-bit	130,000	1978	Feb. 1982	1983	1989	1
386	32-bit	275,000	1982	Oct. 1985	1986	1992	5
486	32-bit	1.2 million	1986	April, 1989	1990	1995*	20
Pentium	32-bit	3.1 million	1989	March 1993	1994	1997*	100
P6	64-bit	5.5 million	1990	Q3 1995	1996*	1999*	250*
P7	64-bit	10 million*	1993	1997 or 1998*	1998 or 1999*	2002*	500*

* Estimate.
** MIPS stands for Million Instructions Per Second.
***This is actually the 80286 but usually just called the 286. The 80386 and 80486 are similarly abbreviated.

Table 3: Intel's rapid introduction of new generations of Intel microprocessors. Sources: Intel Annual Reports and product briefs; *Business Week* (Feb. 20, 1995).

[9] *Wall Street Journal.* October 17, 1995.

[10] Intel's profits for 1995, estimated at more than $3.5 billion, while inviting entry, also suggests that it has even more money to fight entry by, for example, building the very expensive plants.

The landmark ruling by Judges Ingram and Gray that microcode is copyrightable made it very difficult for competitors to imitate Intel's designs. This makes it very difficult for competitors to design a microprocessor that can run all the software that PC users have accumulated over the years that only run on an Intel architecture, of which its microcode is a critical part. The switching cost to another machine is high. Because microprocessor design is very complex, trying to circumvent the microcode makes the task of designing it even more formidable. With the protection of its copyright and continued generational product innovations, Intel does not have to depend on its manufacturing competence—a competences that is usually critical following the emergence of a dominant design. That is, although Intel has invested heavily in manufacturing and does very well in it, its competence in manufacturing alone is not sufficient to give it a competitive advantage.

4.2 Micron Technology

In 1987, Micron Technology was the only U.S. DRAM maker with manufacturing operations in the U.S.[11] In the year ending August 1995, it earned $805 million on revenues of $2.8 billion. One reason for Micron's survival during the 1980s and subsequent thriving in the mid 1990s is the series of strategic decisions that the firm has taken since entering the DRAM business, some of them in response to the U.S. environment that was not conducive to post-dominant design performance. Founded by Ward Parkinson, who designed DRAMs for innovator Mostek, Micron introduced its first DRAM in 1982. To offer the low cost dictated by the nature of the DRAM business,[12] Micron decided to capitalize on its competences in design rather than try to out-manufacture its deep-pocketed vertically integrated Japanese competitors. It used its design skills to

[11]The only other U.S. firm producing DRAMs, TI, did so outside the U.S. in a Japanese fab, using a Japanese design. Motorola signed an agreement in November 1987 to package and distribute Toshiba DRAMs.

[12] Unlike microprocessors, DRAMs do not have a microcode that is protected by US copyright laws. Appropriability of DRAM patents is weaker although, as we see shortly, TI has been able to capitalize on its DRAM intellectual property.

create what has been described as a "phantom" fab. To see how the firm was able to use its design competences to compensate for its manufacturing disadvantage, it is worthwhile briefly recapping how chips are manufactured.

4.2.1 Manufacturing chips

To manufacture a chip, the very intricate patterns required to build its electronic infrastructure must be transferred to the surface of a silicon wafer. Figure 2 shows a wafer and the chips (called die) that are etched unto the wafer's surface. For each wafer, these intricate patterns must be transferred layer upon layer. Since each layer of intricate patterns is added to all the die on each wafer at the same time, the more die there are on it, the lower the cost per die. All else equal, the smaller the die size (and therefore the more die per wafer) and/or the fewer the number of layers that have to be etched onto the wafer, the less each chip will cost. The cost savings come from at least two sources. First, they come from the "die economies of scale"—more die on a wafer whose cost has not changed—and from the fact that for the same wafer, the number of costly layers is down. Second, they come from the reduction in the number of defective die. How? A dust particle one-five-hundredths the diameter of the human hair would look like a boulder on any of the electronic highways of the chip's infrastructure, effectively destroying it. The larger the chip, and the more layers it takes to etch the pattern onto it, the higher the chance that such a dust particle or any other defect will destroy the chip.

Much of Micron's success has been attributed to the firm's ability to use its design competences to get more die per wafer, while also keeping the number of layers it takes to process each wafer at a minimum. In so doing, it produces low cost chips without the first-class manufacturing know-how of its Japanese competitors. We now explore these strategies.

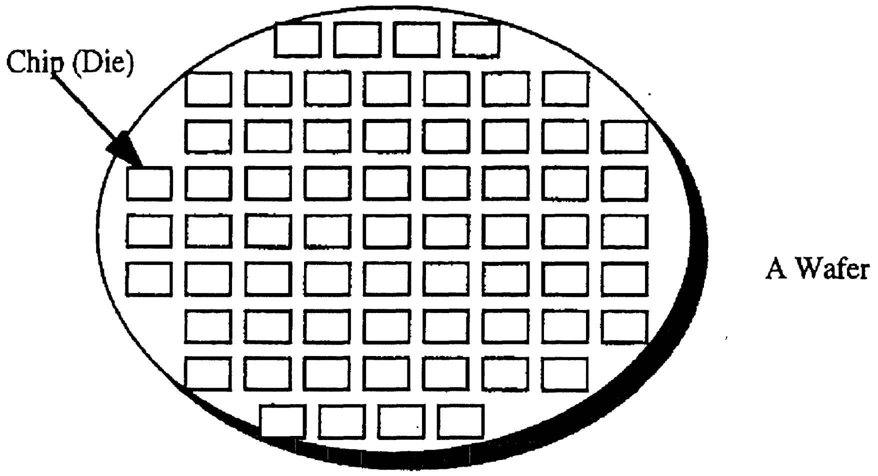

Figure 2: A wafer with many chips (die) on it. All the chips on a wafer are processed in parallel.

4.2.2 Compensating for the lack of manufacturing competences

Usually, shortly after a new generation of DRAMs has been introduced, engineers redesign it to make the die smaller. This reduction of the die size is normally called a shrink. Micron's strategy was to use its design expertise to not only offer the smallest die possible for any generation of DRAMs, but also to ensure that the number of layers required to etch the die patterns onto silicon wafers is kept to a minimum. For example, the firm performed four shrinks of its 4M DRAM compared to an industry average of two per DRAM generation.[13] It also managed to reduce the number of layers for that design to twelve, compared to an industry average of eighteen.[14] This strategy allowed the firm to offer low cost products without having to be at the forefront of manufacturing technologies. For example, when its competitors were moving from 6-inch (diameter) wafers to 8-inch, in order to reduce their cost (by having more die per wafer), Micron did not have to do so right away since it already had a lot of die per wafer on its 6-inch wafers. An early move would have required better relations with suppliers of critical equipment such as lithography aligners and investments in new fabs and new equipment—all of which could

[13]*The Economist* (1995b): Semiconductors: Remind me how to make money. *The Economist*. August 26, 1995.
[14]Davis, Dwight B (1993): Micron's Formula. *Electronics Business*. March 1993

be very costly to first movers and difficult for U.S. firms since most of the suppliers of such equipment were Japanese.

4.2.3 Protecting its position

Micron's strategies to improving its competitive position were not limited to exploiting its design competences. Like Intel, it took to the courts. Following a crash of the PC market at the end of 1984, Japanese firms were left with overcapacity in DRAMs. In 1985, they dropped the price of 64K DRAMs from $2 to 25 cents in the U.S. U.S. firms charged that Japanese firms were dumping DRAMs in the U.S.—selling them for less than they cost to produce in Japan. In 1985, Micron filed a $300 million suit against six Japanese chipmakers—Hitachi, Fujitsu, NEC, Mitsubishi, Oki, and Toshiba—charging that they had conspired to monopolize the DRAM market and drive U.S. manufacturers out of business in violation of parts of the Sherman Act, the Clayton Act , the Wilson Tariff Act, and the Antidumping Act of 1916.[15] The International Trade Commission upheld the dumping complaint. The Semiconductor Industry Association (SIA) also filed an unfair-trading complaint with the U.S. trade representative. U.S. and Japanese officials reached an agreement that was signed in August 1986.[16] The agreement stipulated that Japan had to open its markets to American DRAM makers and that Japanese firms had to sell DRAMs in the U.S. at or above prices fixed by the U.S.'s Department of Commerce.[17]

4.2.4 Implications of Micron's strategic actions

Micron's actions had some important effects on its environment and its competitiveness. First, the floor prices allowed Micron to be competitive again. The firm has since then, like Intel, been taking legal action against firms that it feels are violating its patents.

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[15]Zipper, Stuart (1985)

[16]*The Economist* (1988): Big Prices for Wee DRAMS.*The Economist*. February 27, 1988

[17]Setting floor prices for DRAMs has been criticised by economists as being inefficient and hurting DRAM users such as Sun Mcirosystems. Micron did not see things that way..

Partly as a result of the law suit by Micron and subsequent events, Sematech was established in 1987 with a $100 million dollar contribution from the U.S. government, with member firms contributing the other $100 million. The goal of Sematech was to help build a local environment that was more conducive to such post-dominant design activities as manufacturing, and related industries. Finally, it led to TI's decision to use the courts to help it stay competitive.

4.3 Texas Instruments

In the late 1970s, TI was the top ranked semiconductor manufacturer in the world. With the onslaught of competition from Japanese firms, it saw its leadership position quickly erode. Like Micron, TI went to court; and like Intel, it struck alliances with competitors.

4.3.1 Protecting its intellectual property

By the time TI lost its leadership position, it had accumulated thousands of patents. In 1986, following Micron's successful suit against Japanese firms and the subsequent establishment of a price ceiling for DRAMs sold in the U.S., TI filed a law suit against NEC, Mitsubishi, Sharp, Fujitsu, Hitachi, Oki, Toshiba, and Samsung claiming infringement on its patents issued between 1970 and 1985.[18] All of these firms eventually settled out of court, with many of them agreeing to pay royalties to TI.

With its success in suing Japanese and Korean firms, TI turned to U.S. firms, filing a suit against Micron in November of 1988 with the same claims it had labeled against Japanese firms. This was settled in May 1989 with Micron agreeing to pay royalties. Next, it filed a suit against Analog Devices, Cypress Semiconductor, Integrated Device Technology, LSI Logic, and VLSI

[18]These patents were: No. 3,541,543, for a binary decoder; No. 3,940,747, a high-density, high-speed random access read-wire memory; No. 4,081,701, a high-speed sense amplifier for MOS random access memory; No. 4,240,092, a randomaccess memory cell with different capacitor and transistor oxide thickness; No. 4,249,194, an integrated circuit MOS capacitor using implanted region to change threshold; No. 4,249,376, a carrier for integrated circuits; No. 4,533,843, a high-performance dynamic sense amplifier with voltage boost for row address; andNo. 4,543,500, also a high-performance dynamic sense amplifier. (See Kidd, J.D and Ristelhueber, Robert: Japanese Split on TI Patents; NEC Counters. *Electronic News*, March 31. 1986.

Technology for infringing on patents it had been awarded on the plastic encapsulation process used to seal chips in plastic protective packaging.

4.3.2 Implications of law suits

The benefits of TI's strong protection of its intellectual property have been threefold. First, between 1987 and 1994, it collected royalties of $1.9 billion compared to an operating income of the $1.3 billion that it earned during that period. With so much money coming from royalties, TI effectively had the deep pockets that had been the advantage of vertically integrated Japanese firms in building new fabs. Second, by sending a signal to the industry that it would vigorously defend infringement of its intellectual property, TI was making sure that competitors would stay away from its patents and in doing so, be slowed down in the DRAM race. Finally, TI also used the patents to negotiate cross-licensing agreements and strategic alliances that allowed it to obtain manufacturing capabilities in Japan and stay in the DRAM race. For example, in 1987, it settled its suit against Hitachi with a cross-licensing agreement which led to an agreement in 1988 to jointly develop a 16M DRAM.[19] Both firms have since then co-developed a 16M, 64M and are now co-developing a 256M.

In addition to the Hitachi alliances, TI has a joint venture with Acer, a Taiwanese firm and Nipon Steel of Japan or DRAM development and manufacturing.

4.4 Role of product technology

It is also important to note the role of technology in the strategies pursued by the semiconductor firms. Microprocessors exhibit network externalities with customer switching costs that increase with installed base. (These switching costs come from the software that customers accumulate over the years, the investment in learning an operating system, and the development tools that designers of microprocessors build.) Above all, its microcode is copyrightable. Thus, a

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[19] *Electronic News* (1987): TI, Hitachi settle DRAM patent suit. *Electronic News*, June 1, 1987. *Electronic News* (1988): TI, Hitachi sign 16M DRAM pact: plan joint development. *Electronic News*, December 26, 1988.

strategy in which firms forge alliances early in the life of their products to win a dominant design can be pursued. Once its design emerges as the dominant design, a firm can prevent imitation of its design by, for example, defending its intellectual property (copyrights from newer generations) in courts. Microprocessors are also extremely complex to design. This makes circumventing copyrighted microcode very difficult. A maker of microprocessors does not have to be the best in manufacturing to have the leading market share but, as a result, leaves money on the table.

DRAMs do not exhibit the same network externalities as microprocessors. Nor do they (yet) have any microcode that can be copyrighted. They are also easier to design than microprocessors and skills in manufacturing, post-dominant design, are critical. Thus, imitating DRAMs is easier and firms have to turn to low cost strategies such as efficient manufacturing, or designs that "substitute" for manufacturing as was the case with Micron. Alliances are formed not to win dominant designs but to make the cost of expensive fabs more bearable and to pool manufacturing competences.

Somewhere between DRAMs and microprocessors are ASIC (applications specific integrate circuits) of which gate arrays are an integral part. These chips are tailored for the specific needs of a customer and often require an investment by customers in learning how to use the tools provided by the chip maker. Customer switching costs can be high and manufacturer-customer relations are critical.

6. Conclusion

This paper explored why the U.S. regained its leadership position in the semiconductor industry. The strategic decisions taken by Intel, Micron Technology and TI in protecting their entrepreneurial rents were shown to have both a direct and indirect effect in enabling them to stay competitive and eventually contribute to the resurgence of the U.S. semiconductor industry. Directly, the strategies allowed the firms to overcome an environment that was not conducive to post-dominant design performance. Indirectly, they influenced the local environment which, in turn, impacted industry success.

The research suggests that it was a series of decisions by each firm, and reaction by the U.S. government, that allowed these firms to stay in the industry and stage a comeback—not one decision by one firm. In particular, Intel's strategic alliances and the design of a 16-bit microprocessor that could use the less costly and more readily available 8-bit complementary chips, may have led to IBM's choice of the Intel architecture and subsequent emergence of the Intel architecture as the standard. It was the firm's decision to defend its intellectual property that led to the landmark case by Judges Ingram and Gray—that microcode is copyrightable, giving Intel the intellectual property protection it needed. It was Intel's decision to accelerate the development of newer generations of microprocessors, that has allowed the firm to stay ahead of competitors. It was its decision to build brand identity with its *Intel Inside* that is also further differentiating its products. And as Intel has grown strong, so have local semiconductor companies that offer complementary chips and local related industries such as PC software.

It was Micron's strategy to use its design competences to compensate for its limited manufacturing ability and its decision to sue its Japanese competitors for dumping DRAMs in the U.S., and the subsequent U.S. seeking of and obtaining the agreement that created price ceilings, that allowed Micron to remain in the industry. Micron's decision to go to court also reminded TI that even DRAM patents might be appropriable. TI went to court and successfully prosecuted Japanese and Korea semiconductor companies that had infringed on its DRAM patents. The result was hefty royalties that between 1987 and 1994 amounted to $1.9 billion compared to the firm's operating income of $1.3 billion. It also used the patents to bargain for a successful alliance with Hitachi.

Thus the health of a nation's industry is a function, not only of the environment that the nation provides, but also of the series of strategic decisions taken by firms in protecting their entrepreneurial rents in the industry. These decisions not only allow them to thrive in the industry, they also influence their proximate environment which, in turn, impacts their performance.

REFERENCES

Afuah, A., 1995, *Profiting From Innovation: Fundamentals, Strategies And Implementation.* (Book Manuscript, University of Michigan).

Anderson, P. and M. Tushman, 1990, Technological Discontinuities And Dominant Designs: A Cyclical Model Of Technological Change, *Administrative Sciences Quarterly*, vol. 35, no. 4, pp. 604-633.

Barney, J. B., 1991, Firm Resources and Sustained Competitive Advantage, *Journal of Management*, 17, 1, PP. 99-120.

Borrus, M.G., 1988, *Competing for Control: America's Stake in Microelectronics* (Ballinger, Cambridge, MA).

Burgelman, R.A., 1994, Fading Memories: The Process Theory of Strategic Business Exit in Dynamic Environments, *Administrative Sciences Quarterly*, 39, pp. 24-56.

Clark, K.B., 1985, The Interaction of Design Hierarchies and Market Concepts in Technological Evolution, *Research Policy,* 14, pp. 235-251.

Cool, K and D. Schendel, 1988, Performance Differences Among Strategic Group Members, *Strategic Management Journal,* 9, pp. 207-223.

Davis, D.B, 1993, Micron's Formula, *Electronics Business*. March 1993.

Dertouzos, M.L., R.K. Lester, and R.M. Solow, 1988, *Made in America* (MIT Press, Cambridge, MA).

Electronic News, 1987, TI, Hitachi settle DRAM patent suit, *Electronic News*, June 1, 1987.

Electronic News, 1988, TI, Hitachi sign 16M DRAM pact: plan joint development, *Electronic News*, December 26, 1988.

Ferguson, C.H, 1989, Technological development, strategic behavior and government policy in information technology industries, Unpublished Ph. D. dissertation, MIT.

Garud R. and A. Kumaraswamy, 1993, Changing Competitive Dynamics in Network Industries: An Exploration of Sun Microsystems' Open Systems Strategy, *Strategic Management Journal*, 14, pp. 351-369.

Ghemawat, P., 1991, *Commitment: The Dynamics of Strategy* (The Free Press, New York).

Hariharan, S. and C.K Prahalad, 1994, Strategic Windows in the Structuring of Industries: Compatibility Standards and Industry Evolution in H. Thomas, D. O'Neil, R. White and D. Hurst (editors), *Building Strategically-Responsive Organizations* (John Wiley and Sons, New York).

Harhoff, D., 1991, Strategic Spillover Production, Vertical Integration, and Incentives for Research and Development, Unpublished Ph. D. dissertation, MIT.

ICE, 1995, *Status 1995: A Report on the Integrated Circuit Industry* (Integrated Circuit Engineering, Scottsdale, AZ).

Kidd, J.D. and R. Ristelhueber, 1986, Japanese Split on TI Patents; NEC Counters, *Electronic News* March 31. 1986.

Porter, M.E., 1990, The Competitive Advantage of Nations (The Free Press, New York).

Porter, M.E., 1991, Towards a Dynamic Theory of Strategy, *Strategic Management Journal* 12, pp. 95-117.

Prahalad, C. K. and G. Hamel, 1990, The Core Competences of the Corporation, *Harvard Business Review*, May-June, pp. 79-91.

Quinn, J.B., 1992, *Intelligent Enterprise* (The Free Press, New York).

Rumelt, R., 1991, How Much Does Industry Matter, *Strategic Management Journal*, 12, pp. 167-185.

Teece, D. J., G. Pisano, and A. Shuen, 1992, Dynamic Capabilities and Strategic Management (Working Paper, Haas School of Management, University of California, Berkeley).

Teece, D.J., 1986, Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy, *Research Policy* 15, pp. 285-306.

The Economist, 1988, Big Prices for Wee DRAMS, The *Economist*. February 27, 1988.

The Economist, 1995a, The pizzazz facto, *The Economist*. September 16, 1995.

The Economist, 1995b, Semiconductors: Remind me how to make money, *The Economist*. August 26, 1995.

Thomas L.G., 1989, Spare the rod and Spoil the Industry: Vigorous Competition and Vigorous Regulation Promote Global Competitive Advantage: A Ten Nation Study of Government Industrial Policies and Corporate Pharmaceutical Advantage' (Working Paper, Columbia Business School).

Tirole J., 1988, *The Theory of Industrial Organization* (MIT Press, Cambridge, MA).

Utterback J.M. and A.N. Afuah, 1995, The Dynamic Diamond: A Technological Innovation Perspective, (Working Paper, Sloan School of Management, MIT).

Utterback, J.M. and W. Abernathy, 1975, A Dynamic Model of Process and Product Innovation *Omega*, 33, pp. 639-656.

Utterback, J.M., 1994, *Mastering the Dynamics of Innovation* (Harvard Business School Press, Cambridge, MA).

Wernerfelt, B., 1984, A Resource-Based View of the Firm, *The Strategic Management Journal*, 5, pp. 171-180.

Wilson, R.W., P.K. Ashton and T.P. Egan, 1980, *Innovation, Competition and Government Policy in the Semiconductor Industry* (Lexington Books, Lexington, MA).

Zipper, S., 1985, Micron files $300 million suit against 6 Japanese IC makers, *Electronic News*. Sept 16, 1985.

APPENDIX

SRAMs (Static Random Access Memory)

Like the DRAM, the SRAM is used as storage for executing programs. However, it differs from the DRAM in that it is faster and more expensive, and used in applications where speed is critical enough to warrant the extra cost. These differences stem largely from the way the circuitry that holds the bits of information is constructed. It uses four transistors in each memory cell rather than one as in DRAMs and therefore does not need to be refreshed. Intel is credited with the introduction of the first static RAM in 1969. Earlier versions of SRAMs actually used six transistors per cell. Later innovations were able to reduce the number to four. A dominant design emerged following the implementation of these designs using a technology called CMOS (Complementary Metal Oxide Semiconductor) that consumes less power than the NMOS (N-type Metal Oxide Semiconductor) used in earlier versions of SRAMs.

Once the dominant design emerged, emphasis again passed from product innovation to process innovation. Closer relations with equipment manufacturers became more important. Gradually, the U.S. lost its lead in SRAMs maintaining, in 1994 only 25% of the market (compared to Japan's 62%).

EPROMS (Electrically Programmable Read Only Memory)

The main disadvantage of DRAMs and SRAMs is that, unlike the ferrite core memory they replaced, they are volatile. That is, when power is switched off, they lose whatever data they were carrying. So an interesting question to chipmakers in the late 1960s was how to develop a random access semiconductor memory that would preserve its data even when power has been cut off. Intel's research for this novel device paid off when Dov Frolich-Benchkowsky invented the EPROM in 1971 with the development of the FAMOS (Floating Gate Avalanche injection Metal Oxide Semiconductor) cell. Each bit of the memory device would be represented by the presence or absence of electrical charge on a gate buried in the oxide of a transistor. That first ERPOM needed as many as five power supplies—the larger ones to "force" the charge to the gate, and the other to supply the rest of the chip.

Shortly after Intel's introduction of the EPROM, other firms reverse engineered the product and introduced similar parts. The dominant design emerged with the introduction of the 16K version that needed only one power source. Again, following the dominant design, emphasis shifted from product innovation to process innovation with relationships with suppliers of equipment now becoming critical. Even Intel, the innovator of EPROMs, de-emphasized them in 1991 (Burgelman, 1994). In 1994, the U.S. held only 34% of the market.

Microprocessors

Intel invented the microprocessor in 1972 and shortly after that other firms including Motorola, TI, Zilog and many others entered the market. In the late 1970s and early 1980s, Motorola's microprocessor was the processor of choice for high performance applications such as computer workstations. In 1981, however, when IBM wanted a microprocessor for its personal computer, it chose Intel's architecture. As the popularity of the IBM PC increased, so did that of Intel's microprocessor. In the late 1980s the architecture started dominating the market for personal computers and can be termed the dominant design.

Following the emergence of the Intel architecture as the dominant design, foreign competitors did not take over the microprocessor market for two reasons. In the first place, the microprocessor's microcode is protectable under intellectual property laws and Intel has been able to legally protect its microprocessor copyrights and patents. In the second place, all the software that users of IBM PCs have accumulated over the years cannot run without a lot of effort on other architectures. As such, the switching costs for customers can be high. Thus, Intel and the U.S. have been able to maintain a leadership position in microprocessors despite the emergence of a dominant design and what would have been a shift from major product innovations to process innovations.