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Profitability in the Semiconductor Industry

1 Profitability in the Semiconductor Industry

The profitability of firms in the semiconductor industry depends on a vast array of variables from manufacturing costs to name recognition. Throughout the electronics infrastructure the rules are changing as global competition intensifies, product lifecycles shorten, and technology accelerates. As a result, the management of human resources and compensation approaches change, time-to market becomes more critical, and business strategies are being re-evaluated. Despite the incredible profits of most semiconductor companies between 1993 and 1996, industry over-capacity in 1996 forced company restructuring and workforce reductions, especially among semiconductor equipment suppliers.

In recent years, investors have become very attracted to high technology firms and the stock market is influencing the way companies are doing business. Having become the objects of such close scrutiny, companies are changing their approaches to capital spending and risk.

An analysis of company profitability and the factors influencing it is essential to an understanding of the IC industry and the reasons why cost effectiveness is critical. This chapter first explains the industry's "boom" and "bust" cycles, and the relationship between average selling price (ASP) of devices, capital spending, factory utilization, and profitability. Capital spending trends are reviewed, followed by a discussion of recent industry downsizing and the role the stock market plays in the semiconductor industry.

Changes in product lifecycles, time-to-market and fab cycle time are then examined. Next, typical methods of measuring company profitability are reviewed, followed by a profitability comparison between large and medium-sized semiconductor manufacturers as well as IC equipment suppliers. Finally, the reasons why IC manufacturing is so costly are presented, leading into an expanded analysis of cost per wafer in Chapter 2.

The Profitability Cycle

Long term, the sustained profitability of the semiconductor manufacturers depends on each company's ability to maintain high enough profit margins on the devices it produces to allow sufficient capital outlays for future generations of devices. As will be shown later, depreciation costs are the largest consumer of operating costs and the cost of R&D is increasing. Together these costs can constitute from 25 to 35 percent of annual revenues.

From year to year, the health of the semiconductor industry as a whole is indicated by its characteristic "boom" and "bust" periods, known as the silicon cycle (Figure 1-1). Since 1978, there have been four growth cycles in which sales grew an average of 30 percent per year. Following each growth cycle, the industry experiences a one to two year period when sales growth averaged slightly under 4 percent. ICE expects modest growth in 1997 following the “boom” of 28-41 percent growth in 1993-1995 and 1996’s contraction caused by plummeting memory prices. Over the industry's last 20 years (1976-1996), the growth rate has averaged a healthy 19 percent.

Swings in production growth rate are closely tied to capacity utilization, ASPs of devices and capital spending (Figure 1-2). For the industry as a whole, when capacity utilization is high, ASPs rise and companies are more profitable, which in turn, encourages capital spending. However, with increased spending, capacity constraints loosen and ASPs tend to drop, decreasing company profitability. The decreased profitability (pre-tax income) then reduces the amount of capital available to invest in future needs. This "profitability cycle," and the historical relationships between profitability, utilization rates, ASPs, and capital spending are shown in Figures 1-3 through 1-6 for North American merchant semiconductor manufacturers only.

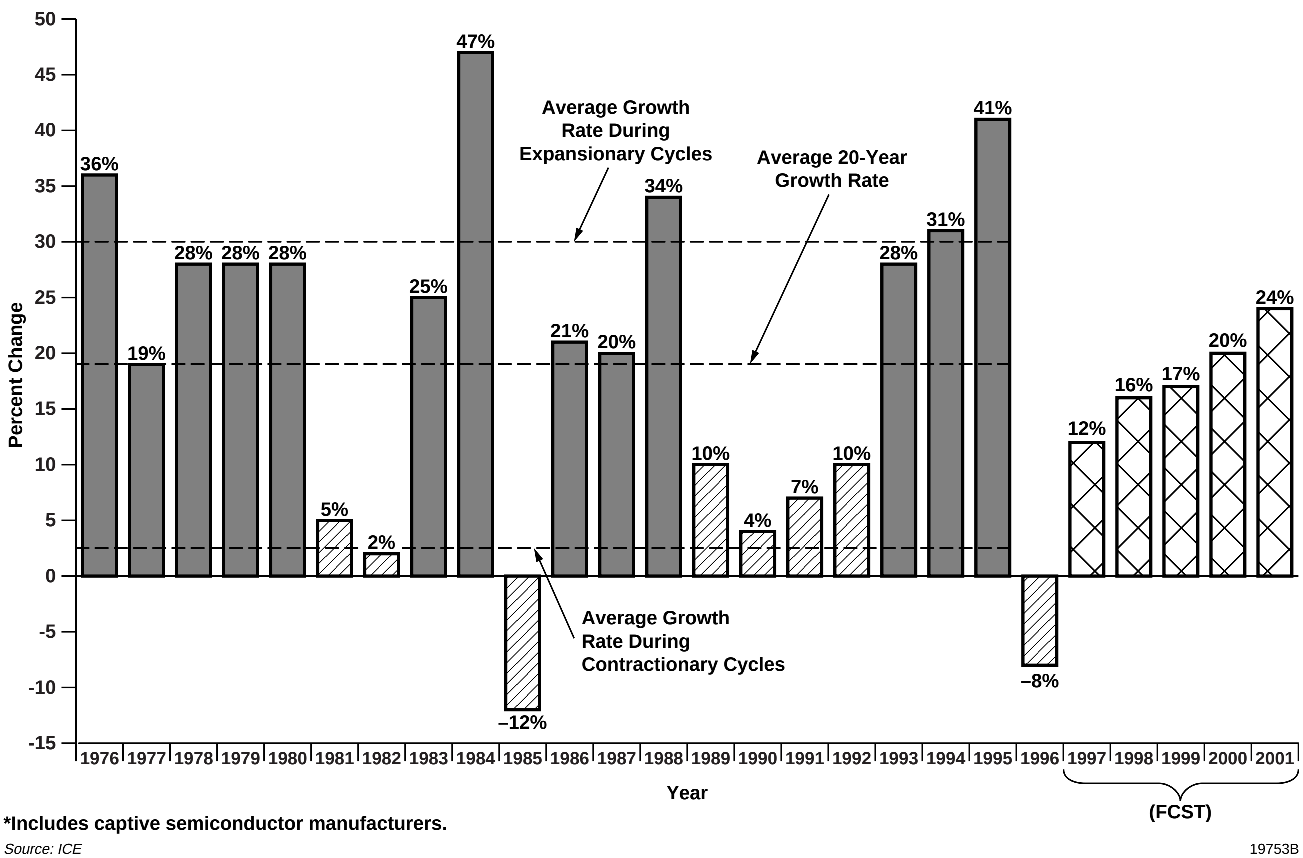
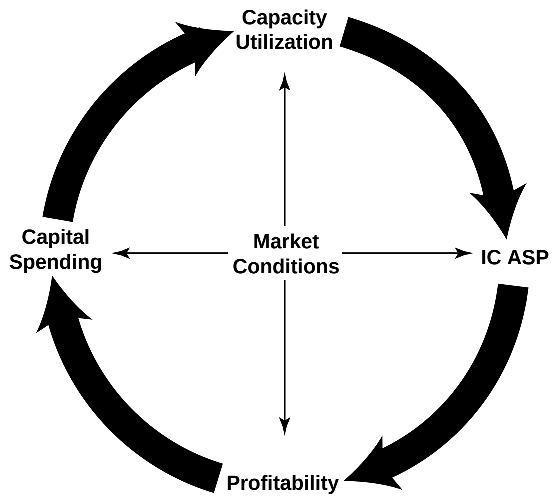


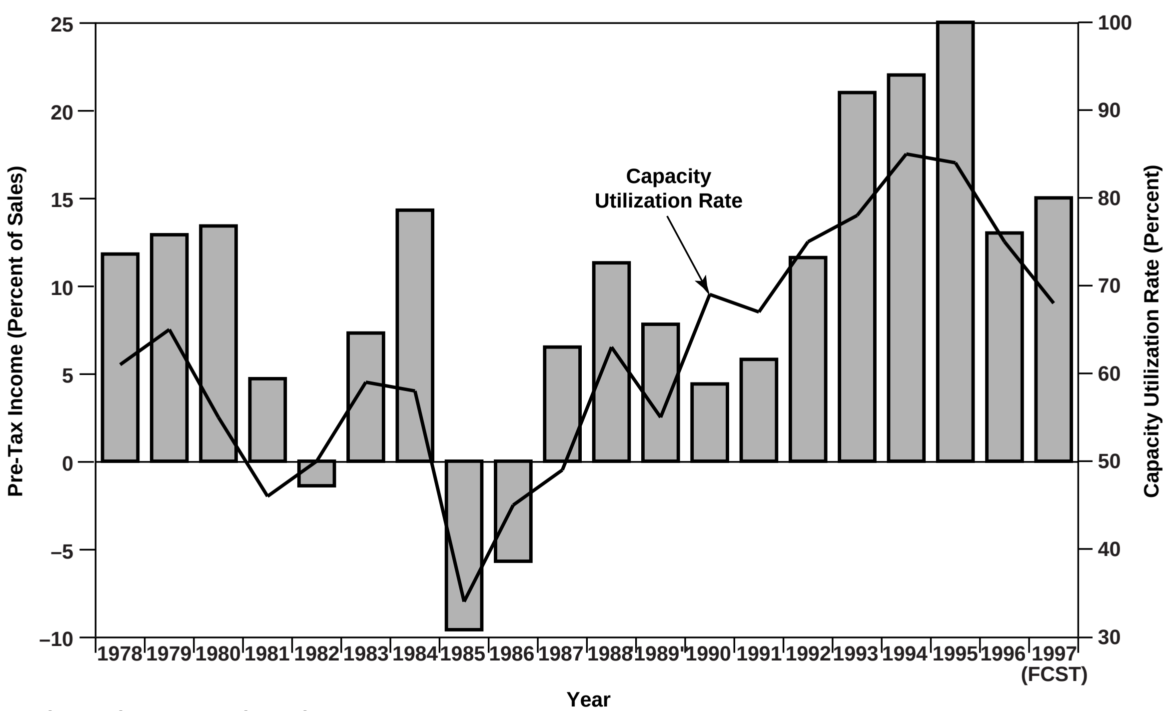
*Figure 1-1. Boom-Bust Cycles of Worldwide Semiconductor Sales**



	1993-1995	1996
Capacity Utilization	Increasing	Decreasing
Total IC Industry ASPs	Strong Increases	Decreasing
Profitability	Increasing	Decreasing
Capital Spending	Strong Increases	Small Increase

Source: ICE 19417B

Figure 1-2. IC Industry "Profitability Cycle"



***North American companies only**

Source: SIA 19782B

Figure 1-3. High Utilization Rates Indicate High Profitability (1978-1997)*

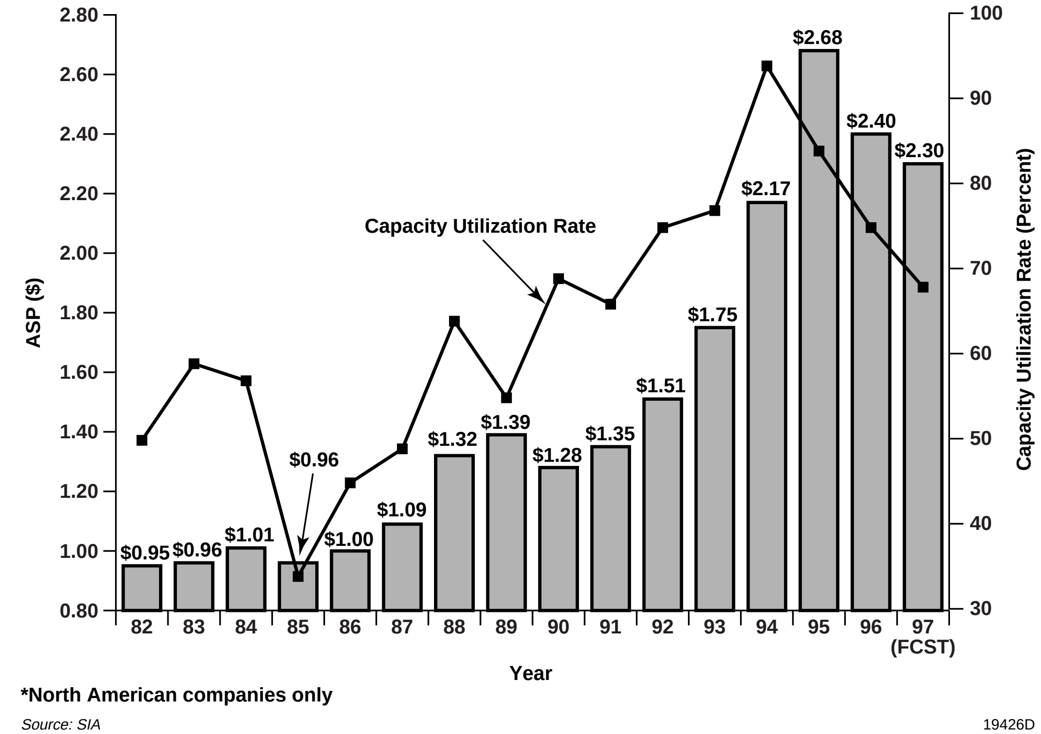


Figure 1-4. IC ASPs Versus Capacity Utilization Rate (1982-1997)*

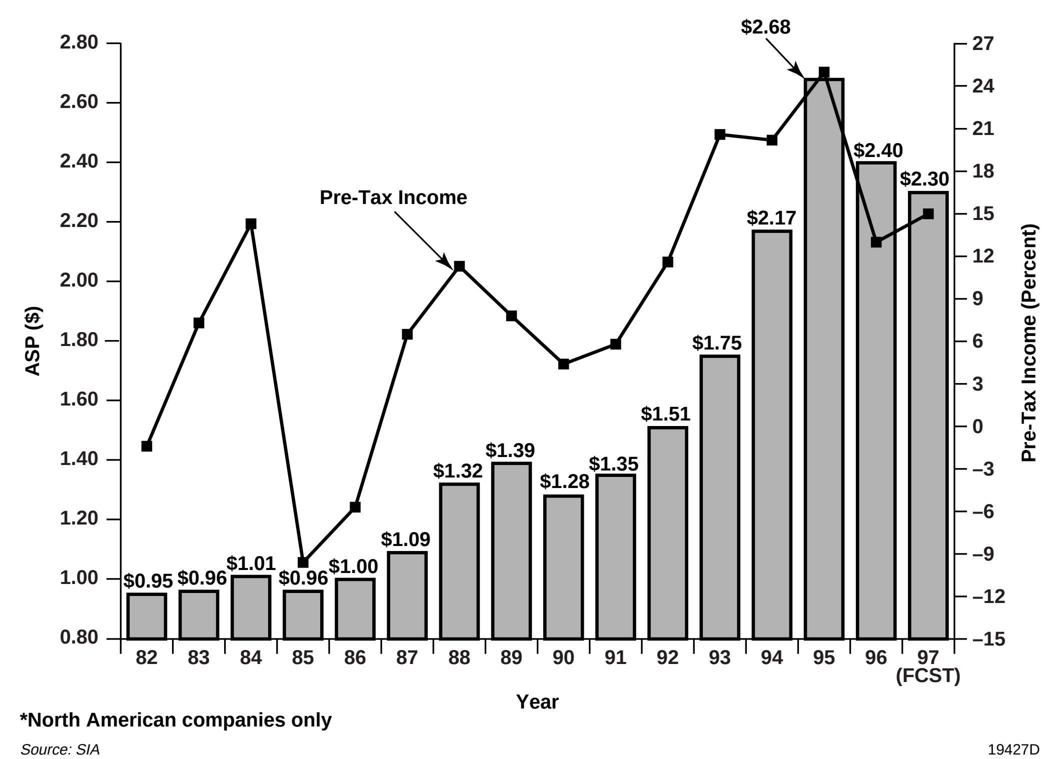


Figure 1-5. IC ASPs Versus Pre-Tax Income (1982-1997)*

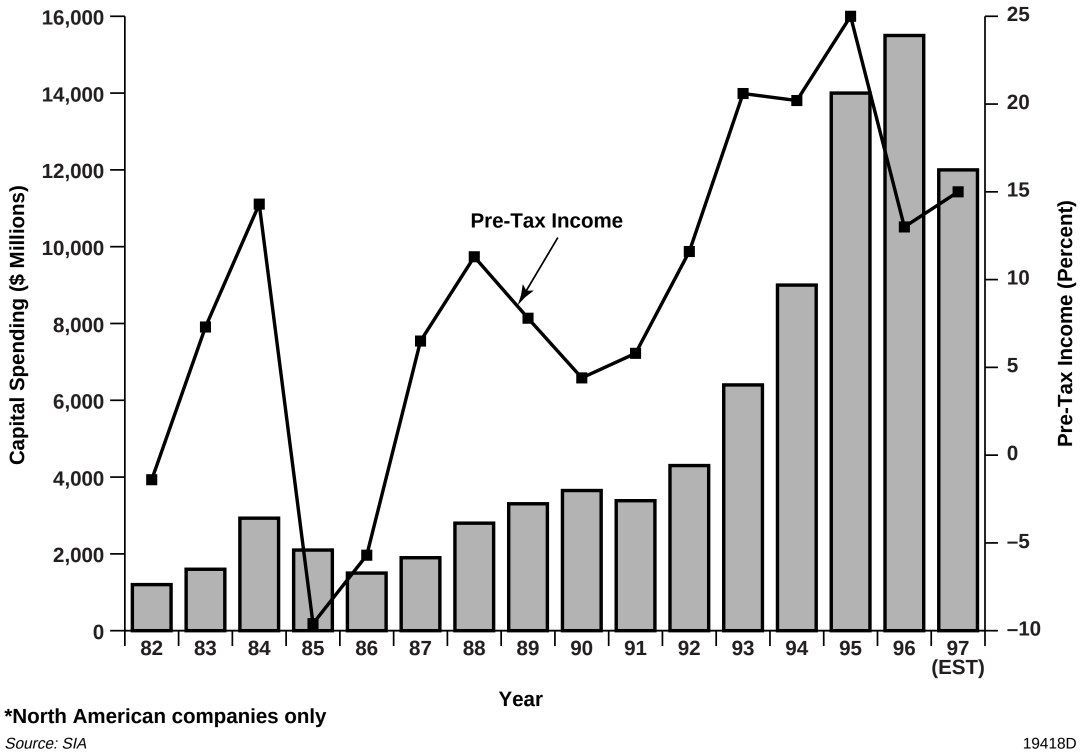


Figure 1-6. Semiconductor Capital Spending and Pre-Tax Income Trends* (1982-1997)

Historically, pre-tax losses are experienced when utilization rates fall below 50 percent, as illustrated in Figure 1-3. However, making utilization projections based on past boom periods is risky as industry growth over the 1993-1995 period was unprecedented. However, ICE's sources indicate that fab utilization is dropping rapidly. This is especially true among memory fabs as the move to future generations of devices (i.e., 64M, 256M and 1G DRAMs) is happening faster than ever and device shrinks are more dramatic than they have been in the past. DRAM manufacturers are implementing these shrinks to improve the margins on DRAM devices, whose ASPs plummeted in 1996 (Figure 1-7). For instance, the first-generation 64M devices were approximately 200mm^2 in size (about 300,000mil^2), while the smallest 64M in 2Q '97 was 123mm^2 (about 190,000mil^2), according to ICE's laboratory analysis of the parts. As more companies adopt this strategy, more fab capacity will be freed to allow production of other devices or the next generation of DRAMs.

For these reasons, ICE feels that despite the healthy conditions in the computer, communications and consumer electronics sectors, utilization in 1996 should fall below 80 percent and will decelerate below 70 percent in 1997. Because these chart reflect North American conditions only, ICE warns that companies highly dependent on DRAM production will probably experience lower fab utilization rates and lower pre-tax incomes. This may be remedied for some companies by the successful transition from memory processing to advanced logic and microcomponent manufacturing. However, because so many companies are adopting this strategy simultaneously, the risk of over-supply in other device markets is quite high. Figure 1-8 shows worldwide fab utilization based on information from over 46 semiconductor manufacturers in North America, Japan, Korea, Taiwan, and Europe, as tracked by a new worldwide capacity study, SICAS (Semiconductor International Capacity Statistics).

Corresponding with the lower utilization of fab capacity, ASPs dropped from an average of $2.68 to $2.40 from 1995 to 1996, and ICE expects an average ASP of $2.30 in 1997. Pre-tax incomes were cut nearly in half from 1995 to 1996, due almost exclusively to the dramatic changes in the memory market. ICE expects pre-tax income to increase slightly from 13 percent to 15 percent from 1996 to 1997. It further forecasts that capital spending by North American firms will significantly drop from 1996's level of $15.5 billion to $12 billion in 1997.

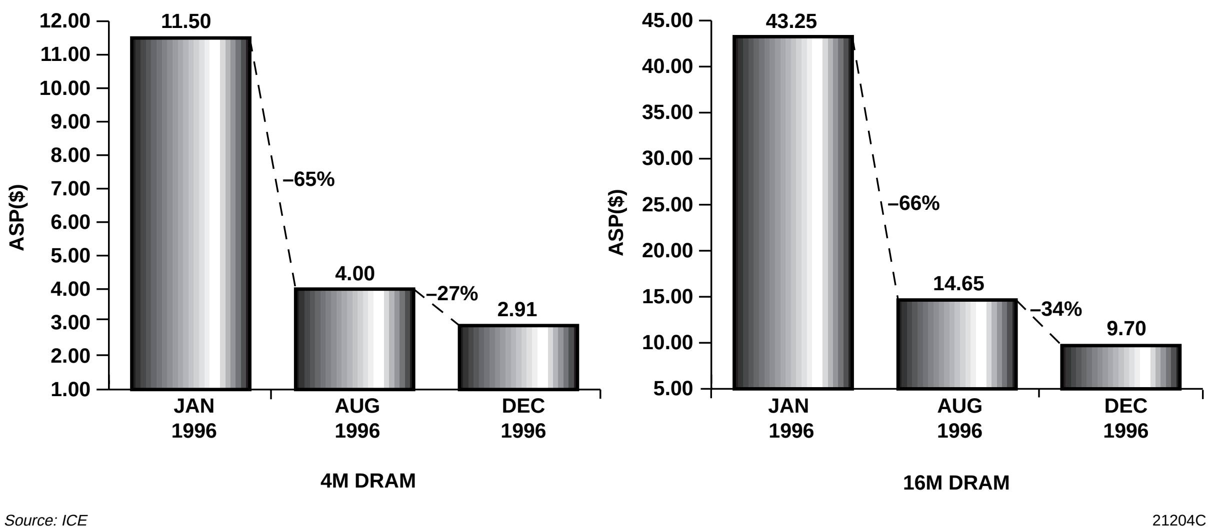


Figure 1-7. DRAM ASPs Plummet

Wafer Type	Capacity Utilization* (Percent)				
	1H94	1H95	2H95	1H96**	2H96
MOS <0.7µm	96.3	95.8	97.4	88.4	90.0
MOS ≥0.7µm	95.7	97.2	96.5	90.1	85.7
Bipolar/BiCMOS	86.7	90.9	91.2	85.6	75.1
Total	94.0	95.7	95.9	89.1	86.1

* Figures expressed are for 150mm equivalent wafers.
** Revised 4/97
Source: SIA
20354D

Figure 1-8. Wafer Fab Capacity Utilization

Worldwide Capital Spending

Because of the boom-bust cycles, IC manufacturers must wisely invest during periods of healthy growth, while remaining flexible enough to curtail expenses during periods of downturn. In reality, the industry largely operates in reactionary mode, despite increased communication with distributors and customers, and reductions in inventory levels over the years. The ramp up of over 50 new fab lines in 1995 and 1996, which at first seemed incapable of meeting the insatiable demand for semiconductors, finally resulted in over-supply of the commodity devices, DRAMs, in 1996. Fab delays occurred in cycles throughout 1996 and managers began making adjustments to spending plans almost on a quarterly basis. Capital shipments for equipment were put on hold for 6 months or more, for all but the most leading-edge equipment such as 248nm steppers, high density plasma etchers, and chemical-mechanical polishing tools.

Jim Bagley, President of OnTrak Systems, recently developed a new metric that may provide a leading indicator of industry recessions[1]. The metric, the multi-year percentage change of semiconductor sales divided by the sum of capital expenditures over the same multi-year period, approaches zero approximately a year before an industry downturn (Figure 1-9). Bagley points out that historically device prices rise approximately two years before the downturn. Figure 1-10 shows a metric that ICE has tracked for years, industry-wide capital spending as a percentage of semiconductor sales. This trend illustrates the swings in capital spending and shows how, on average, spending of roughly 21 percent of sales is needed to sustain the industry's growth.

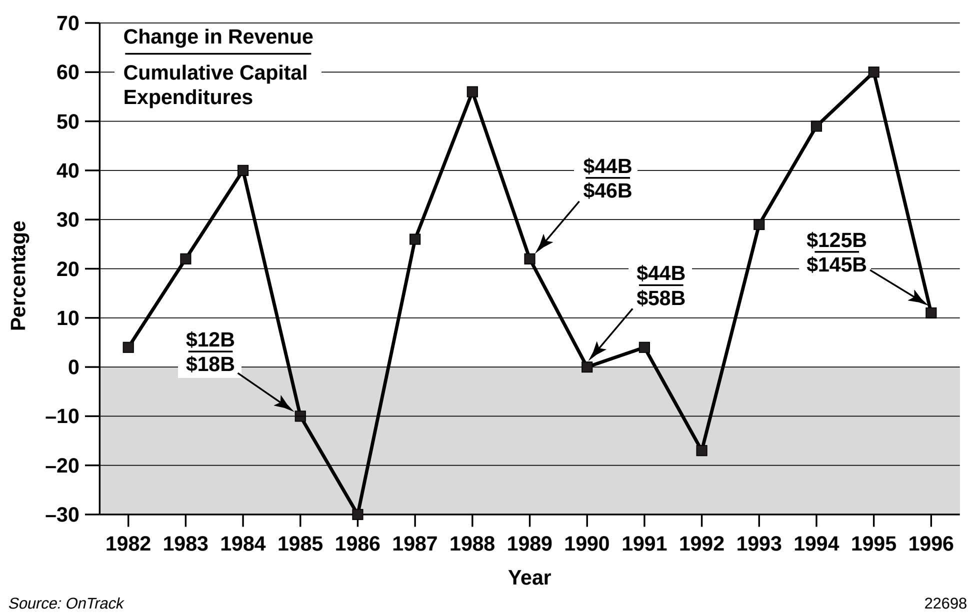


Figure 1-9. Changes in Capital Spending: Indicator of Equipment Industry Health

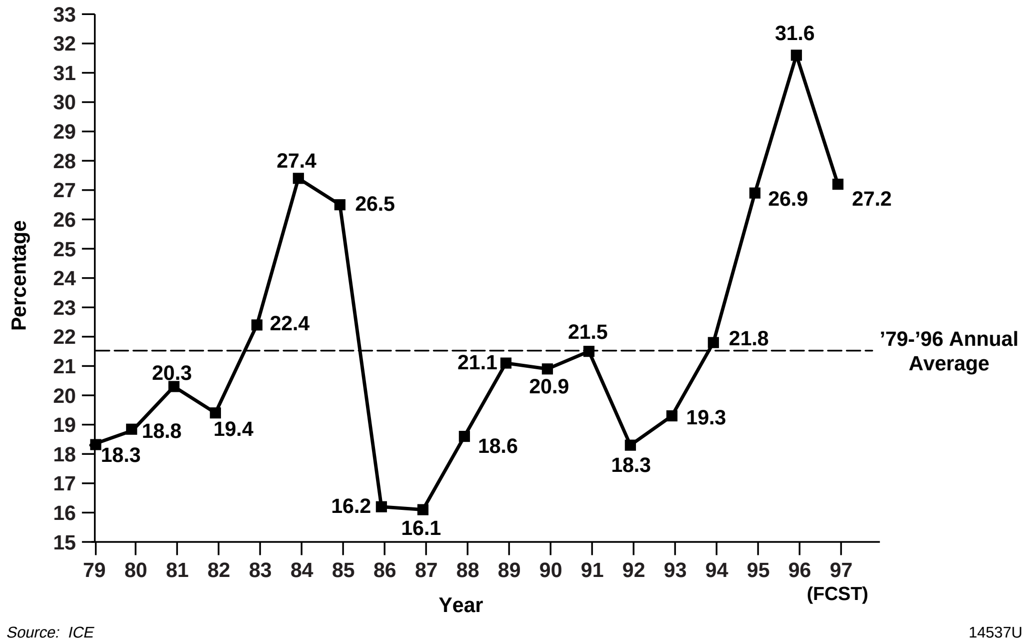


Figure 1-10. Worldwide Capital Spending as a Percent of Worldwide Semiconductor Production (1979-1997)

Figure 1-11 illustrates the recent escalation in capital expenditures, which has increased by 4X in the five year period between 1991 and 1996. In Figure 1-12, one can see the annual changes in capital spending among semiconductor manufacturers. Taiwanese firms (making up the majority of the rest-of-world (ROW) category) have made remarkable inroads in the industry over the most recent years, while Korean companies slowed spending dramatically from 1995 levels, yet still increased it by 10 percent from 1995 to 1996. North American and European firms modestly increased spending in 1996, while Japan decreased it by 4 percent. On a product basis, DRAM spending slowed the most dramatically, while spending for microprocessors, by Intel primarily, remained staunch. Spending for flash memory, DSPs, MOS standard cells and microperipherals, as well as other high-value-added devices remained active. Capital spending for foundries that supply a wide variety of value-added products was substantial.

Figure 1-13 shows the details of capital spending by company on a worldwide basis in 1995 and 1996, ranked according to 1996 spending. Among the top spenders, Motorola, Hitachi, National, and NEC reduced spending the most from 1995, while Sharp, TSMC, TI, Siemens, Rockwell, and IBM increased spending the most. The companies in this table account for nearly 70 percent of total spending in the industry.

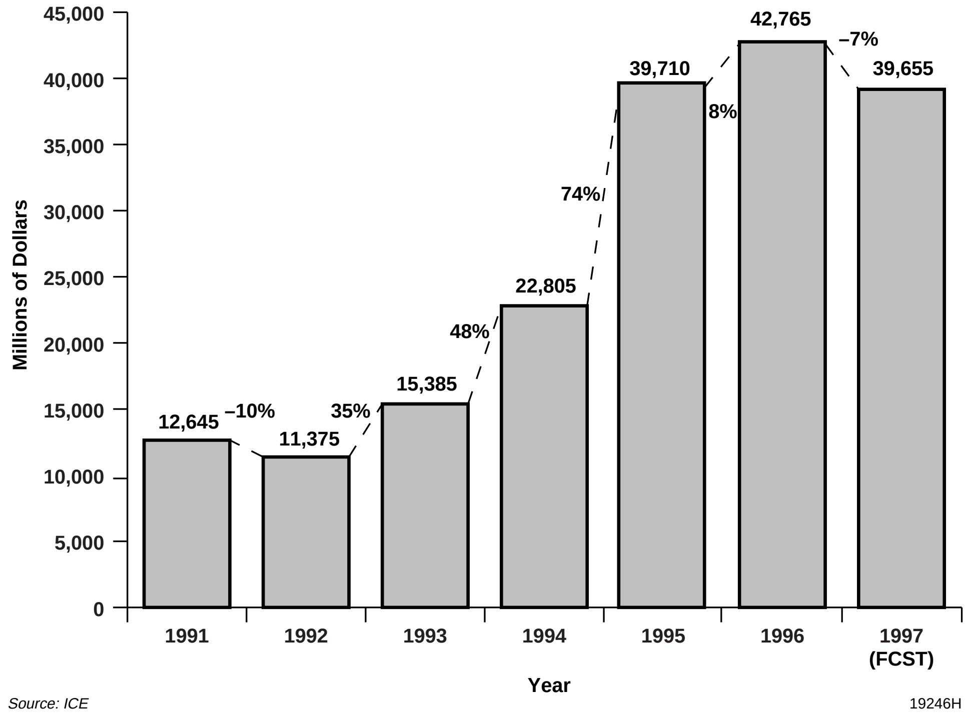


Figure 1-11. Worldwide Merchant Semiconductor Capital Spending Trends

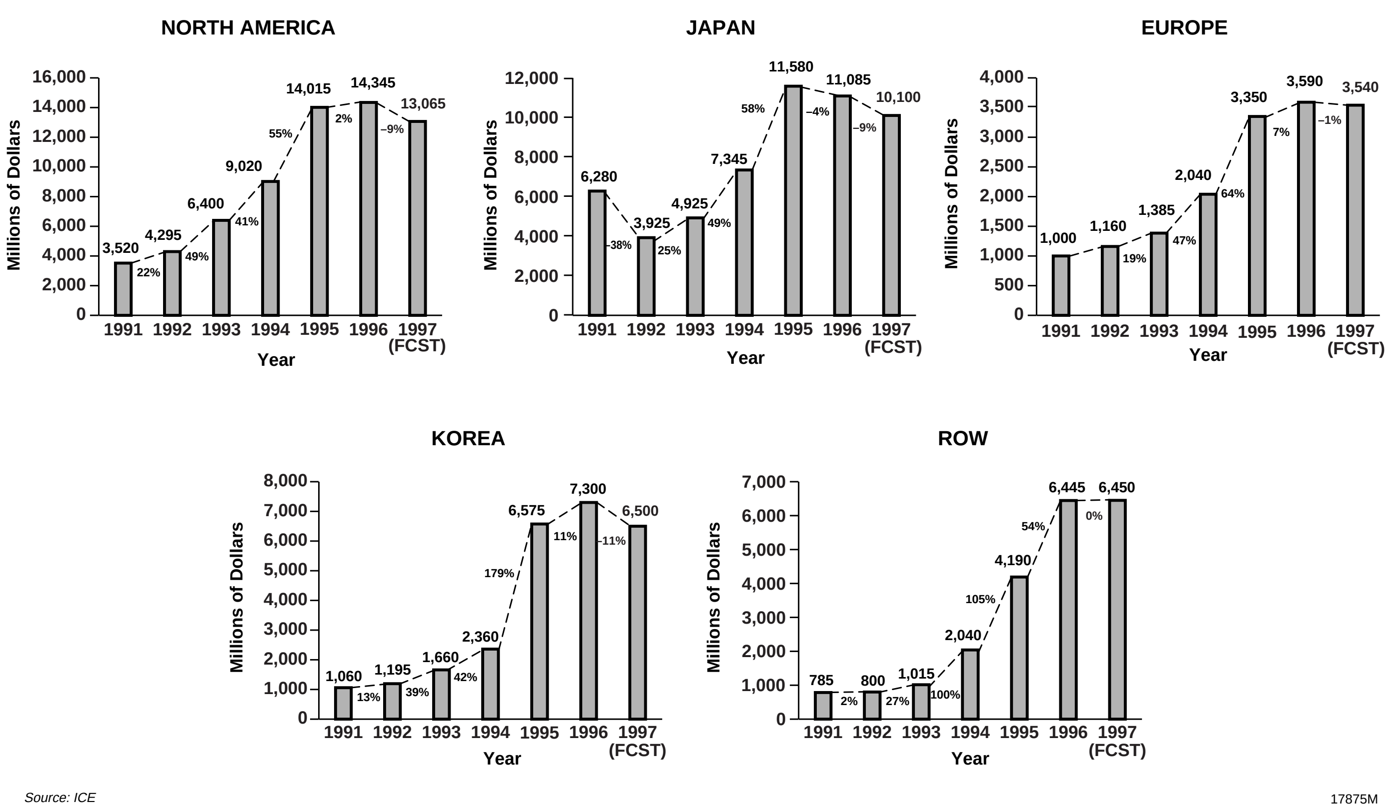


Figure 1-12. Capital Spending by Region

1995 Rank	1996 Rank	Company	1996 Spending ($M)	1995 Spending ($M)	1996/1995 Percent Change	Headquarters
1	1	Intel	3,600	3,100	16	U.S.
4	2	LG Semicon (Goldstar)	2,500	2,100	19	Korea
4	2	Hyundai	2,500	2,100	19	Korea
3	3	Samsung	2,000	2,200	–9	Korea
10	4	TI	1,800	1,150	57	U.S.
5	5	NEC	1,700	2,010	–15	Japan
7	6	Toshiba	1,560	1,545	1	Japan
13	7	IBM	1,500	1,000	50	U.S.
8	8	Fujitsu	1,435	1,505	–5	Japan
2	9	Motorola	1,400	2,350	–40	U.S.
6	10	Hitachi	1,380	1,755	–21	Japan
15	11	Siemens	1,300	850	53	Europe
9	12	Micron	1,160	1,190	–3	U.S.
11	13	Mitsubishi	1,055	1,120	–6	Japan
14	14	Matsushita	1,000	885	13	Japan
12	14	SGS-Thomson	1,000	1,002	—	Europe
19	14	TSMC	1,000	600	67	Taiwan
25	15	Sharp	735	385	91	Japan
20	16	TI-Acer	675	595	13	Taiwan
17	17	AMD	625	621	1	U.S.
21	18	UMC	600	570	5	Taiwan
22	19	Sanyo	595	560	6	Japan
26	20	Rockwell	550	360	53	U.S.
18	21	National	525	620	–15	U.S.
24	22	Mosel Vitelic	520	430	21	Taiwan
16	23	Philips	510	750	–32	Europe
23	24	Sony	460	460	—	Japan

Source: ICE 21960A

Figure 1-13. Capital Expenditures

Viewed from another perspective, the companies with the highest capital spending as a percentage of their annual sales in 1996 is shown in Figure 1-14. All these companies reinvested more than 30 percent of sales in 1996 and three companies spent more than 100 percent of sales! Regionally, Taiwanese and Korean companies increased spending as a percentage of sales the most (Figure 1-15), led by TI-Acer (170 percent), Mosel-Vitelic, LG Semicon, Hyundai, Winbond, and UMC. Relatively speaking, European, Japanese, and U.S. firms, reinvested between 20 percent and 30 percent of revenues on average.

By early 1997, it was evident that spending for DRAM fabs was almost completely on hold and only equipment allowing faster transitions to advanced devices (i.e., 64M and 256M DRAMs) were being purchased. At the same time venture capitalists and investors were becoming slightly less enthusiastic regarding investment in fabs and other semiconductor concerns. However, the proliferation of electronic products and strong growth rates in consumer, computer and entertainment markets exceed those of most other industries, intriguing investors tremendously.

1996 Rank	Company	1996 Capital Spending Percent of IC Sales	Headquarters Location	1996 IC Sales ($M)	1996 Capital Spending ($M)
1	TI-Acer	170	Taiwan	6,700	1,800
2	Mosel-Vitelic	140	Taiwan	375	520
3	LG Semicon	104	Korea	2,400	2,500
4	Hyundai	79	Korea	3,150	2,500
5	Winbond	78	Taiwan	450	350
6	TSMC	71	Taiwan	1,400	1,000
6	UMC	71	Taiwan	840	600
7	Micron	67	U.S.	1,740	1,160
8	Siemens	54	Europe	2,400	1,300
9	Macronix	49	Taiwan	4,100	200
10	Matsushita	45	Japan	2,235	1,000
11	IDT	45	U.S.	545	245
12	Fujitsu	44	Japan	3,225	1,435
13	Alcatel Mietec	43	Europe	210	90
14	Sharp	42	Japan	1,760	735
14	Cypress	42	U.S.	535	225
15	Seiko Epson	40	Japan	825	330
16	Rockwell	37	U.S.	1,500	550
17	VLSI Technology	35	U.S.	720	250
18	Samsung	34	Korea	5,800	2,000
19	Atmel	33	U.S.	1,070	350
20	Sanyo	32	Japan	1,885	595
21	Nippon Steel	32	Japan	375	120
21	AMD	32	U.S.	1,955	625

Source: ICE 19559A

Figure 1-14. Top Capital Spenders Ranked by Percentage of Sales

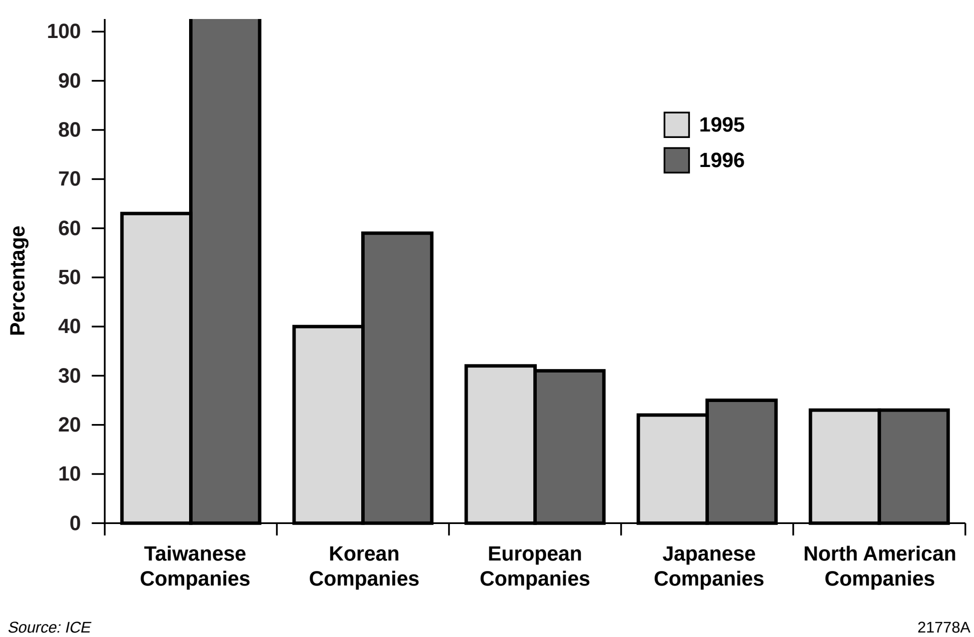


Figure 1-15. Capital Spending as a Percent of IC Sales

The Stock Market and the Changing Nature of the Business

The dawn of a new era in semiconductor history began when a small sticker touting "Intel Inside" appeared on personal computers and their advertisements in the early 1990s. Suddenly semiconductor firms were selling to the average consumer instead of the engineers working for manufacturers of computers and other OEMs. Indeed, once the investment community became fixated on technology stocks, many people realized that the days when engineering prowess ruled were over—and issues such as name recognition and image were evidently gaining importance in the field of semiconductors. Certainly industry followers five years ago would not have imagined a TV commercial showing fab employees in metallic bunny suits dancing around and promoting advanced chip technology, as in a recent Intel advertisement.

Figure 1-16 shows the enormous stock value placed on Intel and Microsoft, the most profitable companies in the high technology sector. Interestingly, their combined market valuations exceed those of the eight well-known companies put together. The combined revenues of these eight traditional companies, roughly $425 million, is 14X the combined revenues of Intel and Microsoft, but merely 2X the profits[2].

But this elite treatment of companies in the semiconductor sector is shared by few companies other than Intel and Microsoft, although IBM has enjoyed outstanding valuation as well. In most other cases, stockholders react dramatically to each development within the companies. Such close surveillance has certain positive effects as companies can gain necessary feedback when a business strategy is tested or when company managers underestimate the importance of time-to-market, for instance. Often, however, such rapid and dramatic responses fail to give companies the support needed to ride-out market changes.

Company	Stock Market Value* ($B)
Microsoft	115.5
Intel	109.3
Total	224.8
General Motors	42.4
Ford Motor	37.5
Boeing	36.6
Eastman Kodak	29.4
Sears Roebuck	20.4
J.P. Morgan	19.2
Caterpillar	15.4
Kellogg	14.2
Total	$215.1

* As of 3/21/97

Source: Wall Street Journal 22629

Figure 1-16. Intel and Microsoft Value Exceeds Eight Traditional Stocks Combined

Industry Downsizing

1995 and 1996 saw initial public offerings by many numerous semiconductor equipment vendors seeking to expand their businesses in order to keep pace with the souring demand for chips. In addition, there were a number of mergers and acquisitions among equipment and materials suppliers. When the over-supply of DRAM devices was realized, fabs were put on hold, capital equipment orders were stalled for 6 months or more, and companies were forced to lay-off a number of employees (Figure 1-17). This followed approximately two years of growth when companies were unable to fill the many positions they had, and had to pay higher salaries as well. Substantial workforce reductions among some of largest equipment suppliers — Applied Materials, Lam Research, Tencor Instruments, and K&S — illustrates the gravity of the downturn. In addition, as small firms such as AG Associates and Genus reduce their workforces dramatically, the future success of these companies and their ability to meet global supply needs comes into question.

A sampling of industry restructuring among semiconductor manufacturers (Figure 1-18) illustrates a similar trend in that smaller firms downsized dramatically in some cases, yet the larger IC manufacturers have not experienced the layoffs of the larger equipment companies. Of course, the very well known exceptions are the layoffs of thousands of employees at IBM and AT&T but these were company-wide layoffs throughout all their divisions. It is also important to note that Lucent Technologies, AT&T's microelectronics division, has been expanding its employee base since the company restructuring

As telling as these tables may be, comparisons between semiconductor equipment vendors and the chip manufacturers must be performed with caution due to the enormous difference in company and industry sizes — semiconductors are a $140 billion industry while equipment is roughly one-quarter its size (Figure 1-19). Figures 1-20 and 1-21 place these two industries in relative context with industries of similar sizes. The semiconductor materials suppliers are slightly less sensitive to market fluctuations because demand changes less radically in this sector. Important exceptions are the wafer manufacturing and photomask manufacturing industries. Wafer suppliers are constrained by polysilicon supply and the long leadtimes for new manufacturing facilities (2-year ramp-ups), while mask suppliers are limited by slow mask writing times, especially when making reticles for the most advanced devices.

Company	Workforce Reduction (Number of Employees)	Percentage of Total Workforce
AG Associates	69	25
Applied Materials	1,700	12
GaSonics	35	7
Genus	39	11
Kulicke & Soffa	300	16
Lam Research	650	11
SubMicron Systems	120	15
Tencor Instruments	220	15
Teradyne	300	6
Unit Instruments	109	22
Watkins-Johnson	75	7

Note: Includes voluntary departures and layoffs of permanent, temporary and contract employees.

Source: ICE 22688

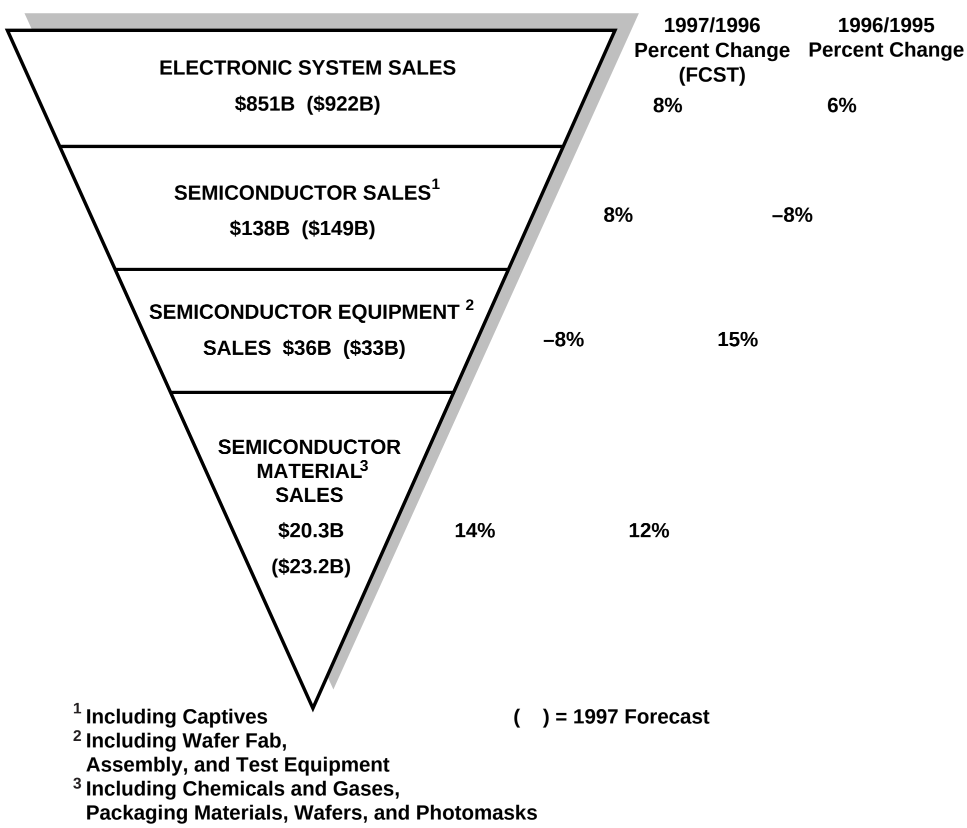
Figure 1-17. Industry Downsizing – Equipment Suppliers

Company	Workforce Reduction (Number of Employees)	Percentage of Total Workforce
Altera	100	11
AMD	250	2
Burr-Brown	60	4
Cirrus Logic	445	13
Cypress Semiconductor	80	9
IMP	89	23
Motorola	545	2
National Semiconductor	600	3
Philips	140	1
Tower Semiconductor	68	10
Weitek	20	30

Note: Includes voluntary departures and layoffs of permanent, temporary and contract employees.

Source: ICE 22687

Figure 1-18. Industry Downsizing – Semiconductor Manufacturers



Source: ICE 13402AC

Figure 1-19. 1996 and 1997 Worldwide Electronics Marketplace

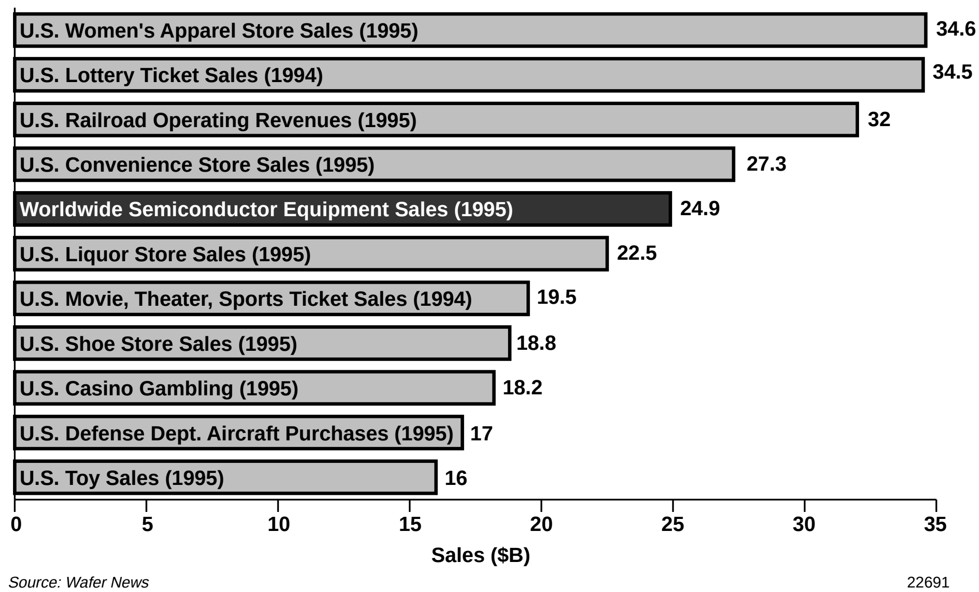


Figure 1-20. Relative View of Semiconductor Equipment Revenues

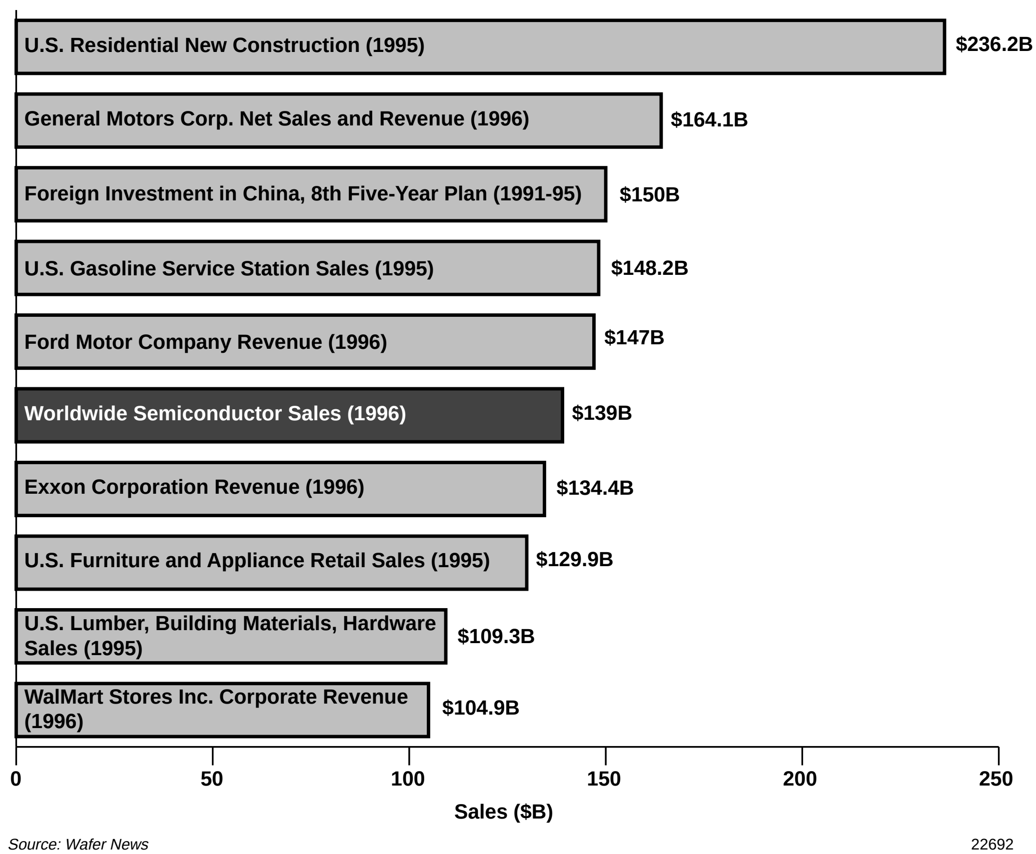


Figure 1-21. Relative View of Semiconductor Revenues

New Approaches to Compensation

Compensation and severance packages are changing, especially among U.S. companies. Years ago, industry downturns were dealt with by dramatic spending cuts, salary freezes, and temporary plant closings, if necessary. Training programs were often cut back. In the 1990s, companies manage downturns in a very different way. Today, training budgets and salaries are not generally cut (although upper managers and CEOs occasionally reduce their pay by some small percentage), yet discretionary spending for outside consultants and other projects are still put on hold. As evidenced by the previous section, layoffs are becoming much more common in the U.S., and stock values of companies typically rise, often dramatically, following company downsizing.

In 1996, IBM's distributed a 1.2 billion bonus among its employees. This payout occurred following several years of downsizing and the layoff of over 5,000 employees. In early 1997, AT&T offered buy-out packages to some 4,000 managers, including $10,000, which could be used for retraining, relocation or financing their own businesses[3]. The company began this strategy approximately a year earlier as a larger plan of efforts to eliminate about 17,000 jobs. After Intel celebrated its 1996 net income of $5.2 billion it paid $820 million in profit-sharing and retirement contributions to its nearly 50,000 employees worldwide. The company also made all of its employees eligible for its stock-option plan in the future, setting an important precedent for the treatment of employees that enable record-breaking profits[4].

Changing Product Lifecycles and Time-to-Market

Company performance and profitability are increasingly tied to time-to-market, market timing, manufacturing cost reduction, and better utilization of assets. In addition, the ability to recognize and manage product lifecycles is becoming more important as the time available for recovering significant investments shortens. Figure 1-22 shows time-to-market differences between world-class manufacturers and other companies in the same sector. Figure 1-23 illustrates how time-to-market differences may vary according to device market. Unless such differences can be remedied, the less competitive and often smaller companies will lose share of market, a phenomenon already occurring among suppliers of semiconductor equipment and materials. This shift to a smaller supplier base is due in large part to widening differences in global customer service, but also the desire by companies to reduce vendor base as a method of streamlining operations.

Typical product lifecycles in the semiconductor industry followed a bell-curve cycle, yet today these are changing shape to more dramatically upward sloping curves that rapidly plummet (Figure 1-24) better reflect reality in today's marketplace. Depending on the device type and market niche, the identification of the positioning of products along these lifecycle curves is becoming more difficult. However, within the microprocessor market it is clear that new products are being introduced more often than in past generations, and the unit volumes and revenue streams peak earlier and subsequently plummet faster (Figure 1-25). The accompanying changes in performance of Intel's microprocessors is shown in Figure 1-26.

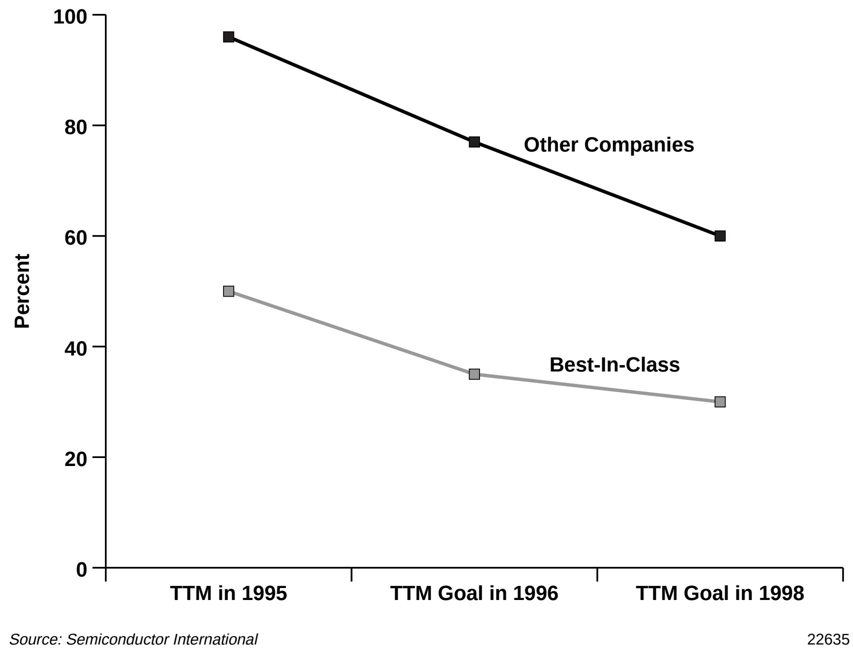


Figure 1-22. Typical Product Time-To-Market

Product Type	Gap Between Best-in-Class Companies' TTM Versus Average Companies' TTM
Microprocessor, Microcontroller, DSP	67%
MOS ASIC	73%
MOS Memory	76%
Analog	55%

Source: Channel Magazine 22704

Figure 1-23. Time-To-Market Performance Gap

It is probable that DRAM devices may venture away from the traditional lifecycle curves of today (Figure 1-27) to one in which the bit volumes peak faster, new generations are introduced faster, and bit volumes following the peak plummet faster. The more competition and price pressure in this market, the more likely such a strategy may become. Figure 1-28 illustrates the changing lifecycles of gate arrays and standard cell products offered by Texas Instruments. TI plans to combine standard cores from several different vendors along with their digital signal processing technology, among others, to offer 0.18mm products in 1998.

Figure 1-24. Product Lifecycles

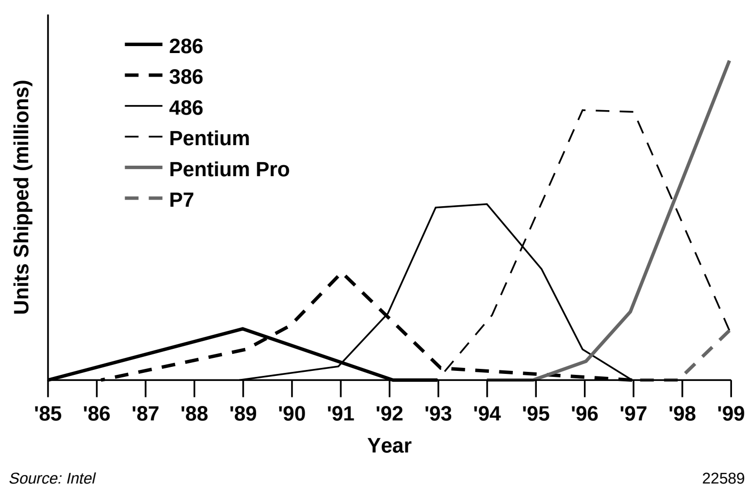


Figure 1-25. Product Lifecycle for Intel Processors

Profitability Trends

An IC manufacturer's profitability is typically measured in:

- Pre-tax income or net income as a percentage of sales,
- Sales revenue per wafer start,
- Sales revenue per employee, or
- Gross margin.

Gross margin is the company's gross profits, or its annual revenues less the manufacturing costs of goods sold. Gross margin, which typically ranges between 20 and 60 percent of sales, allows the company to recoup research and development (R&D) costs, as well as marketing, general, and administrative costs (S, G&A), while hopefully allowing a suitable pre-tax profit. Gross margin for devices is highest when demand is greater than the supply, and/or little competition for the devices exists in the marketplace.

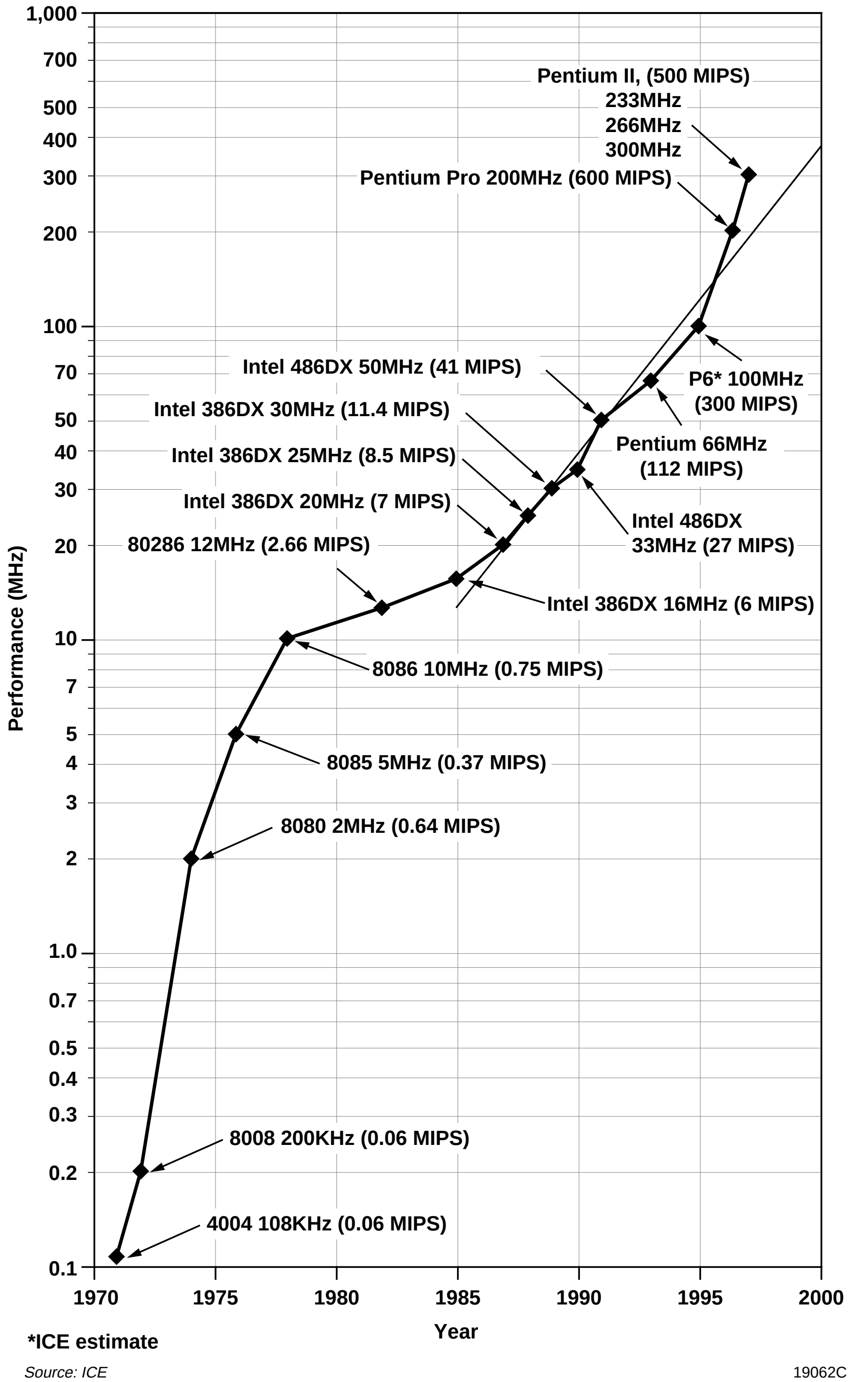


Figure 1-26. Intel MPU Performance Trends

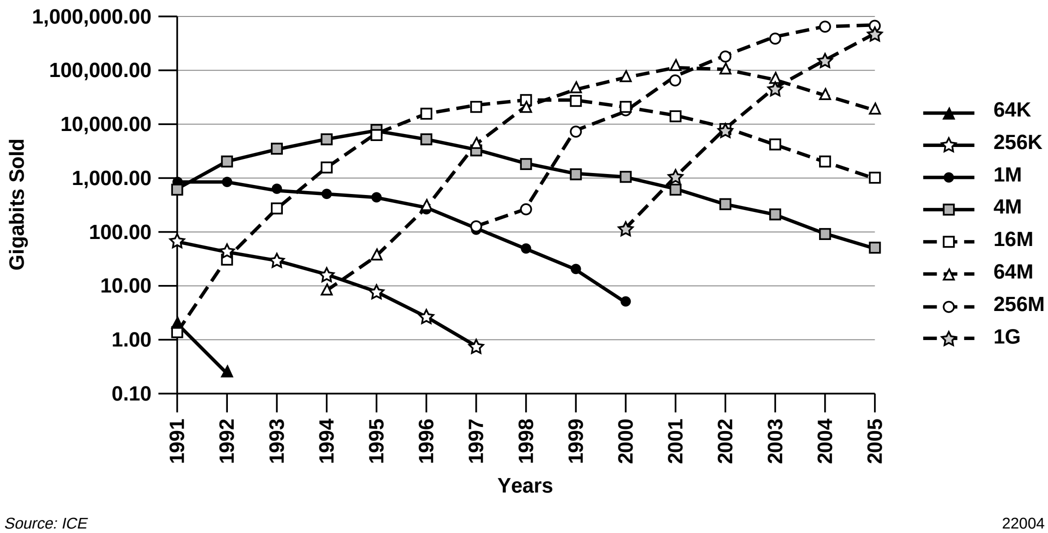


Figure 1-27. DRAM Lifecycles

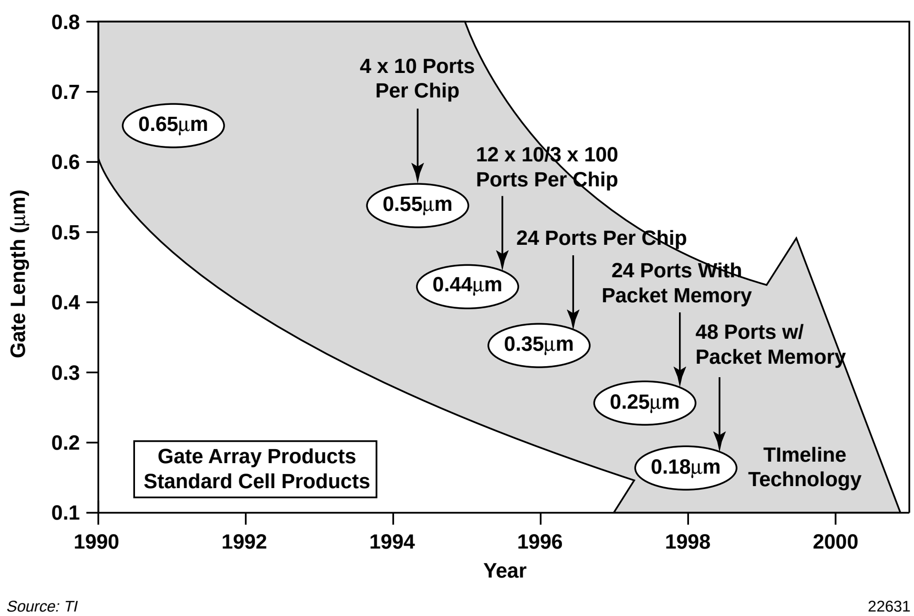


Figure 1-28. 0.18µm Timeline Technology

Figure 1-29 gives examples of net income percentages for Intel, Analog Devices, AMD, and National, all large IC manufacturers, over the last several years. As shown, all four companies were profitable in only four of the fourteen years. Plotting the net income average among these companies indicates surging profitability in the 1991-1995 period, and net income for the four companies averaged 14 percent in 1995 (Figure 1-30). The gross margins for these large IC houses, shown in Figure 1-31, ranged between 42 and 52 percent in 1995, and averaged 48 percent.

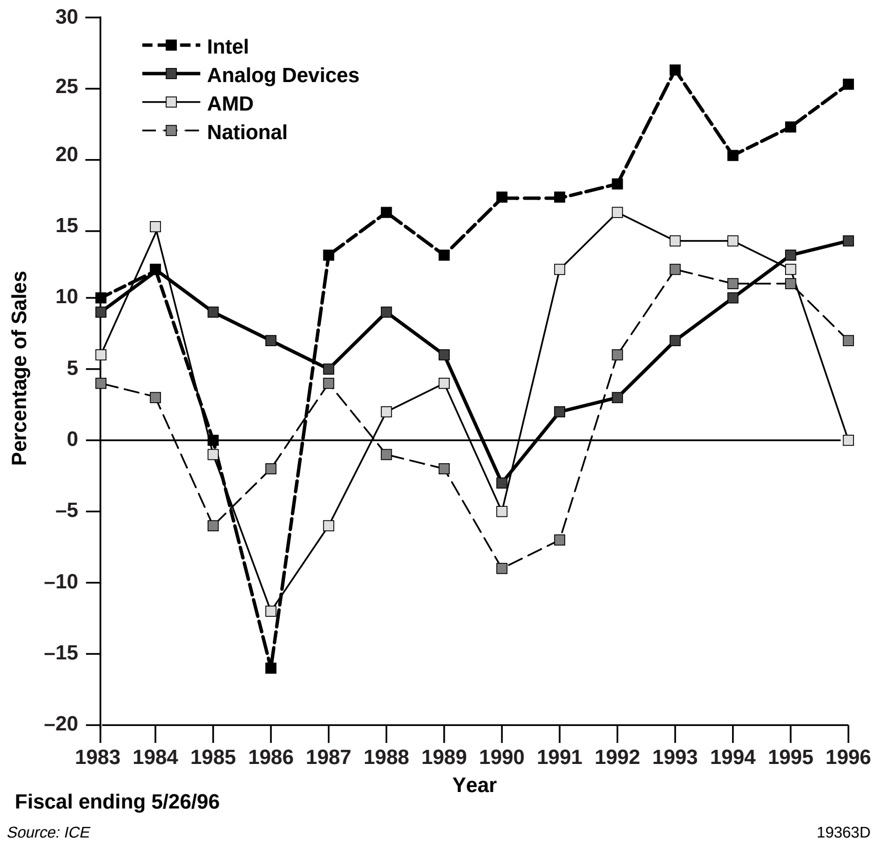


Figure 1-29. Trends in Net Income Percentage (Large Companies)

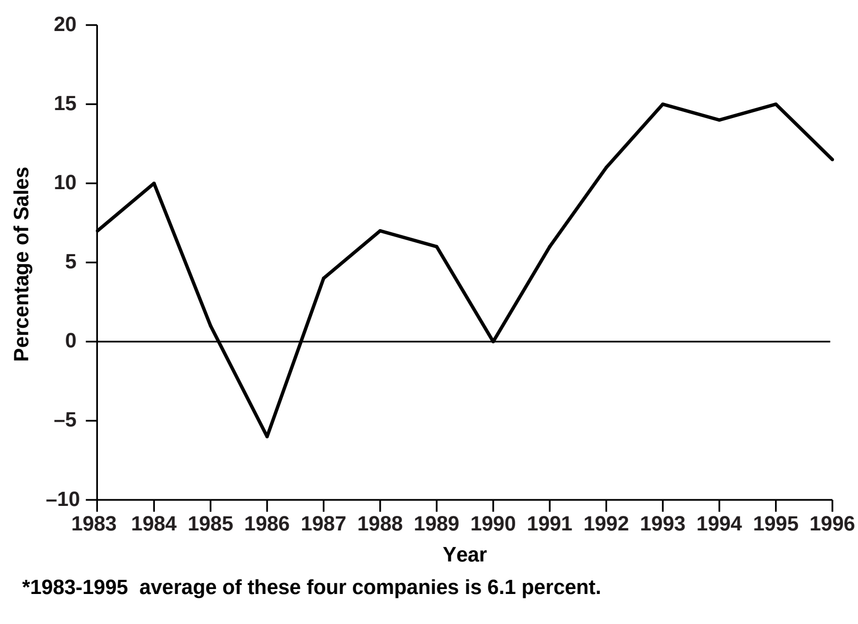


Figure 1-30. Net Income Average of AMD, Analog Devices, Intel, and National*

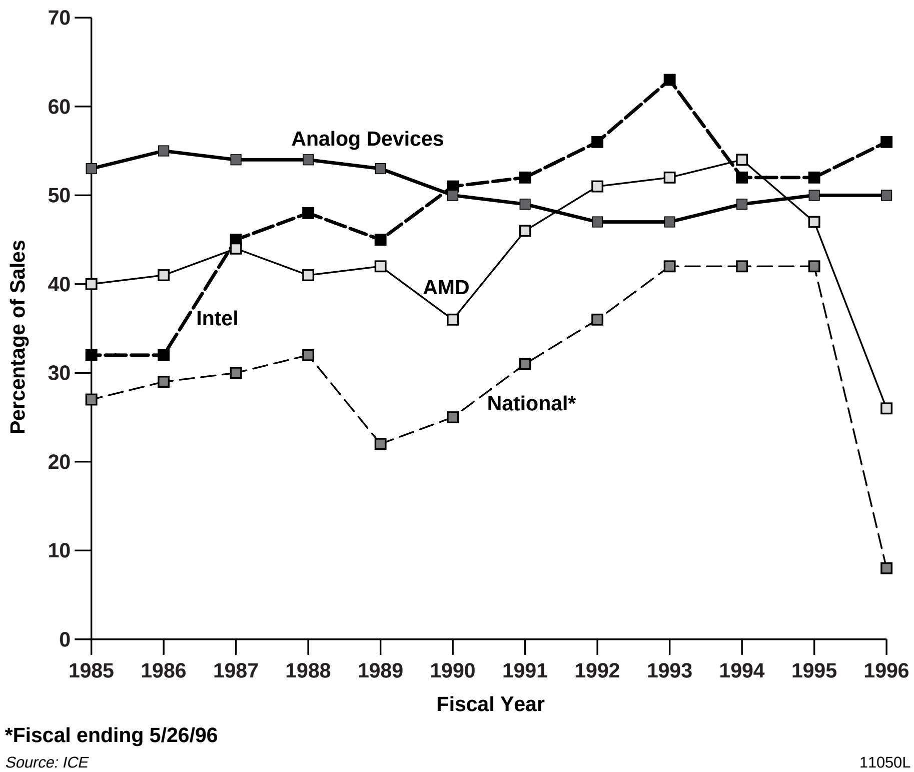


Figure 1-31. Trends in Gross Margin Performance (Large Companies)

Relative to the large IC manufacturers, medium-sized companies, including Cypress, Linear Technology, Micron, VLSI Technology, and LSI Logic, experience larger swings in profitability (Figures 1-32 through 1-34). As shown, Micron has experienced the widest swings in net income -- from –69 percent in 1986 to 34 percent in 1988 -- mirroring the very volatile DRAM market. Interestingly, Micron's net income averaged 25 percent during good years (1988, 1989, 1993, 1994, and 1995) and –18 percent during poor years. LSI Logic's results illustrate how difficult profitability in the ASIC market has been until recently. From 1985 to 1996, the company's net income averaged only 3 percent. Linear Technology, a fabless supplier of specialty analog products quietly realized a 35 percent net income for fiscal year 1996, and a 71 percent gross margin, following outstanding performance over the last four years. All four companies were profitable in six of the twelve years (1988, 1991, 1993, 1994, 1995, and 1996).

Profitability of Equipment and Materials Suppliers

A sampling of the profitability of large and medium-sized (<$200M) equipment manufacturers is shown in Figures 1-35 through 1-39. In general, gross margins of large equipment companies are comparable to those of the semiconductor manufacturers during booming years, yet 1997 is likely to see rapid decreases in net incomes and gross margins, especially among the larger firms. One unfortunate result of the cyclical nature of this industry is the struggle of smaller firms to compete. As the industry has seen over the last several years, typically the largest equipment firms gain share of market following years of downturn.

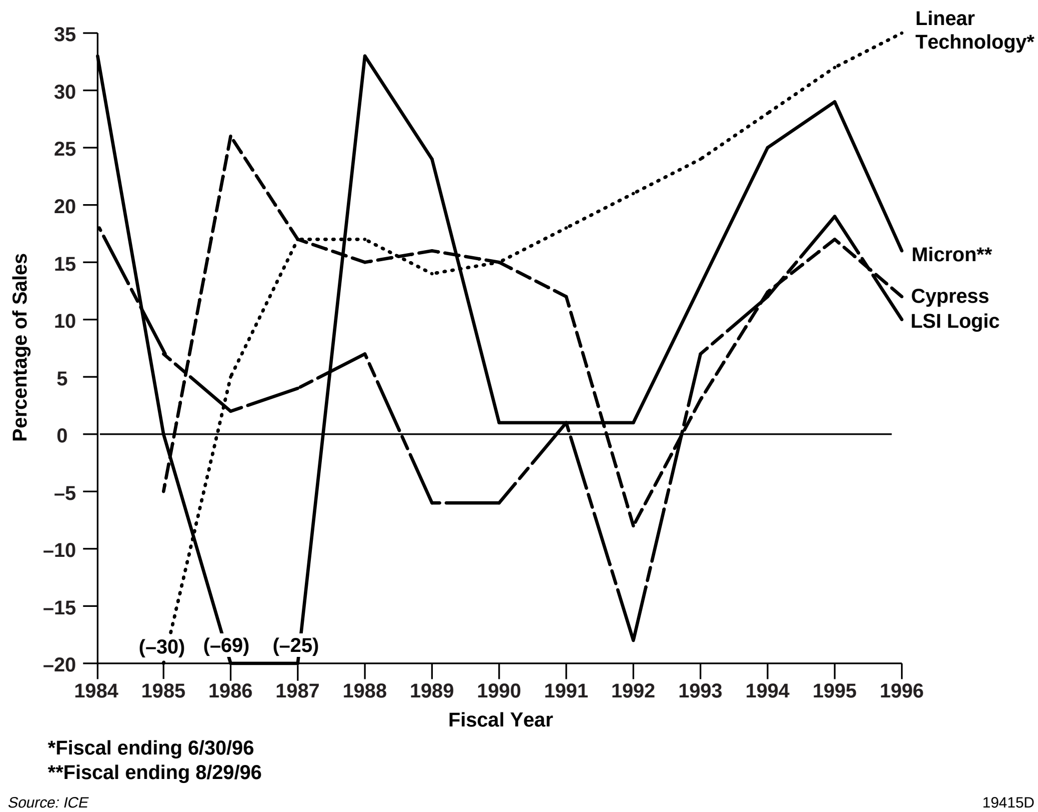


Figure 1-32. Trends in Net Income Percentage (Medium-Sized Companies)

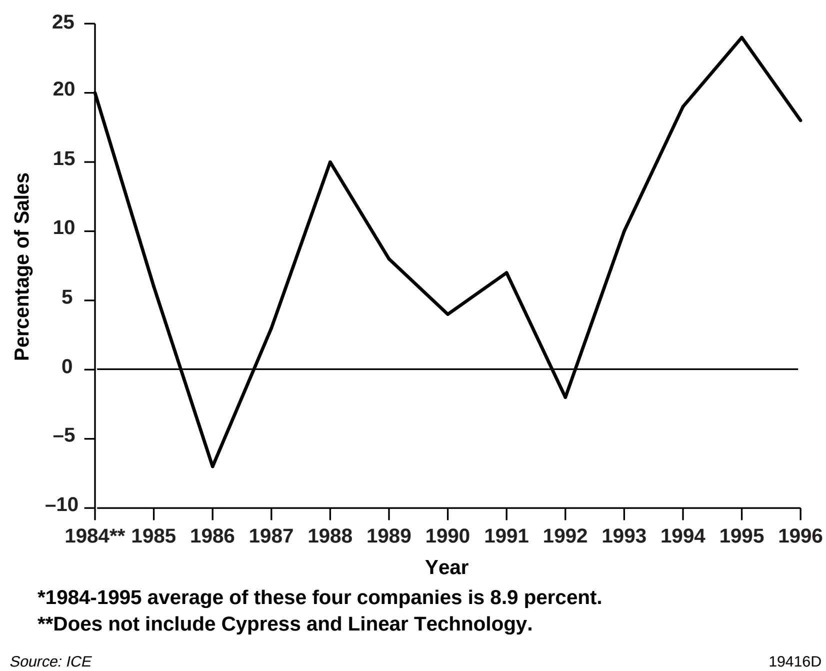


Figure 1-33. Net Income Average of Cypress, LSI Logic, Linear Technology, and Micron*

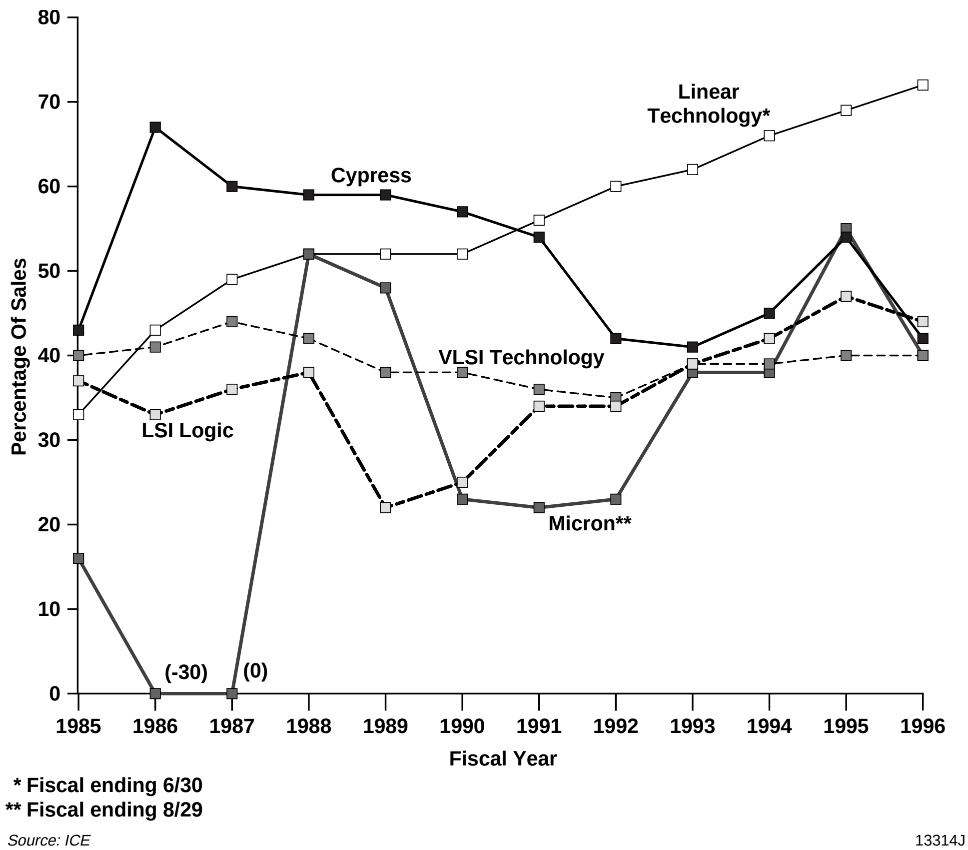


Figure 1-34. Trends in Gross Margin Performance (Medium-Sized Companies)

What is Responsible for Rising Fab Costs?

In recent years, much controversy has ensued over the main cause of rising fab costs. While IC manufacturers typically point to the rising cost of capital equipment, the suppliers claim that higher priced equipment is the inevitable result of increasing demands put on companies for higher performance systems and process development. Who is right?

At least part of this controversy is the result of oversimplification of fab costs. Companies typically refer to the rising cost of constructing and equipping a new, leading-edge fab facility, running over a billion dollars in 1996 (Figure 1-39). Since equipment accounts for an increasingly larger percentage of new fab costs, up around 80 percent in 1996 (Figure 1-40), many people choose to equate rising equipment costs with rising fab costs.

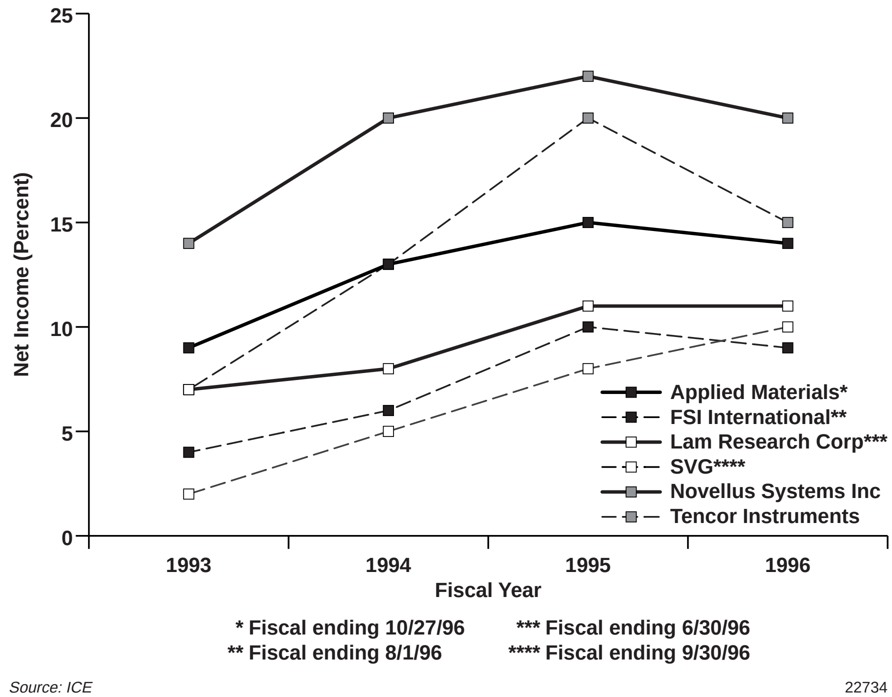


Figure 1-35. Net Income as a Percentage of Revenues (Large Companies)

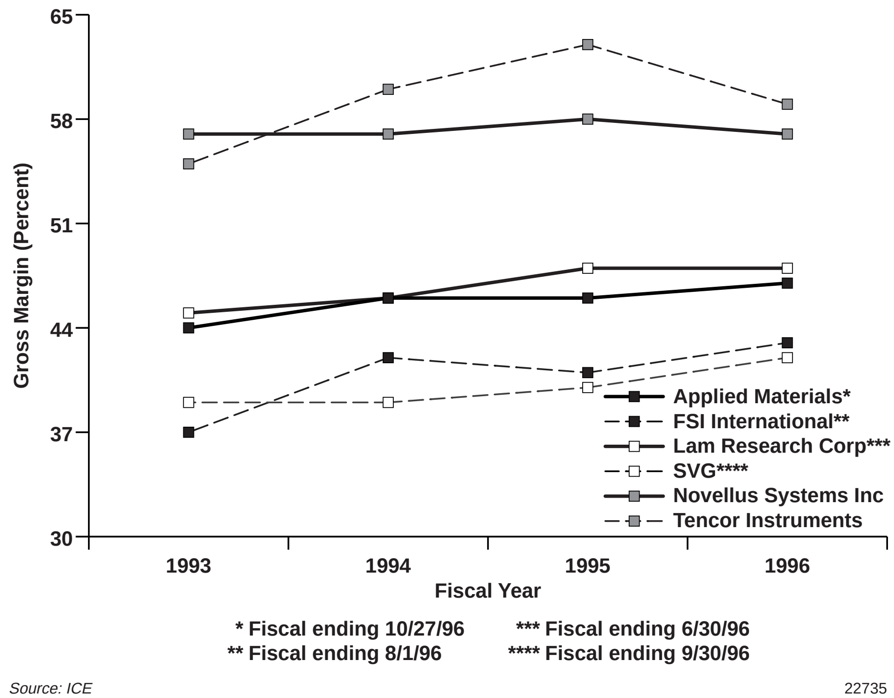


Figure 1-36. Gross Margin as a Percentage of Revenues (Large Companies)

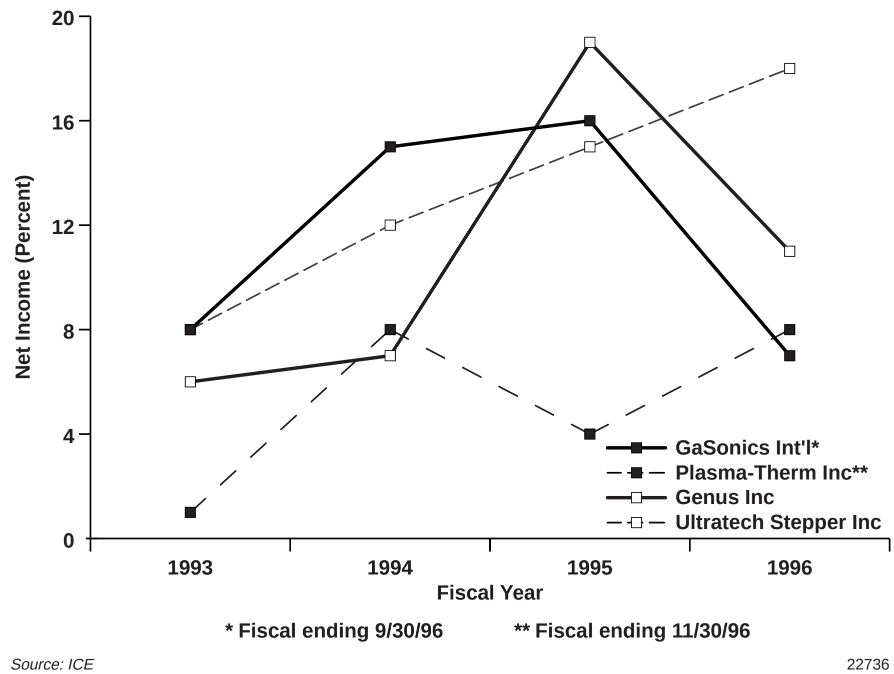


Figure 1-37. Net Income as a Percentage of Revenues (Medium-Sized Companies)

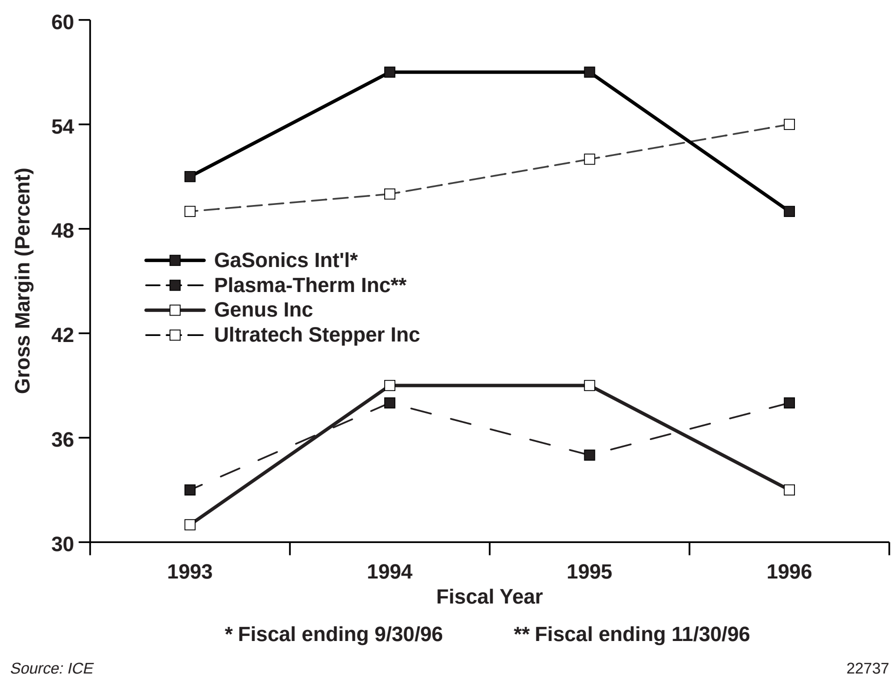


Figure 1-38. Gross Margin as a Percentage of Revenues (Medium-Sized Companies)

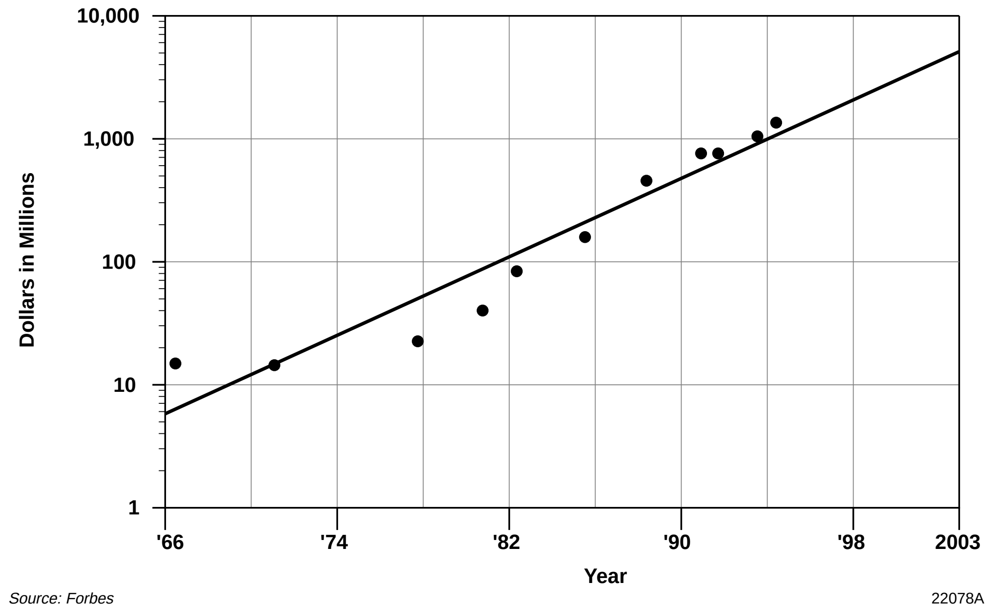


Figure 1-39. Cost of Semiconductor Factories

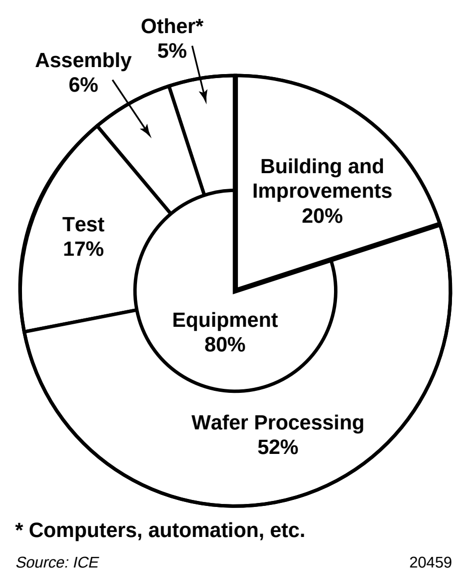


Figure 1-40. Breakdown of Semiconductor Capital Expenditures

As it turns out, although equipment costs do increase by approximately 50 percent each device generation, rising equipment investments is not the sole reason for rising manufacturing costs. Shrinking device lifecycles, increasing chip sizes, shrinking design rules, and the increasing cost of higher purity materials — all significantly contribute to rising manufacturing costs. Figure 1-41 summarizes the key factors contributing to the total investment in IC manufacturing. The most important is high technology, or the ongoing investment in device designs, new equipment, and cleanroom facilities needed to fabricate the increasingly complex semiconductor devices.

Fortunately, the increasing cost of manufacturing is off-set by the ability to continually integrate more functions per square centimeter of silicon, known as Moore's Law. For memory devices, this is manifested in the decreasing cost per bit of memory (Figure 1-42), and with microprocessors, a decreasing cost per million instructions per second (MIPS). The trend of decreasing cost per bit of memory, approximately 1.3X per device generation, or decreasing cost per MIPS, approximately 1.4X per generation occurs in tandem with a rapidly progressing increase in device complexity (Figure 1-43). Today, that means that Intel can spend five times as much to develop and manufacture Pentium microprocessors as it spent producing the 486 chips (Figures 1-44 and 1-45)—and still make a profit.

However, the margin between decreasing cost per function and manufacturing costs is shrinking dramatically. In addition, as the useful lifetime of this equipment decreases (because chip lifecycles are shrinking), the length of time available to recover investments shortens. For these reasons, it appears that while historical trends in device scaling will prove to be technically feasible, the profitability of semiconductor manufacturers depends more on the proper management of manufacturing costs.

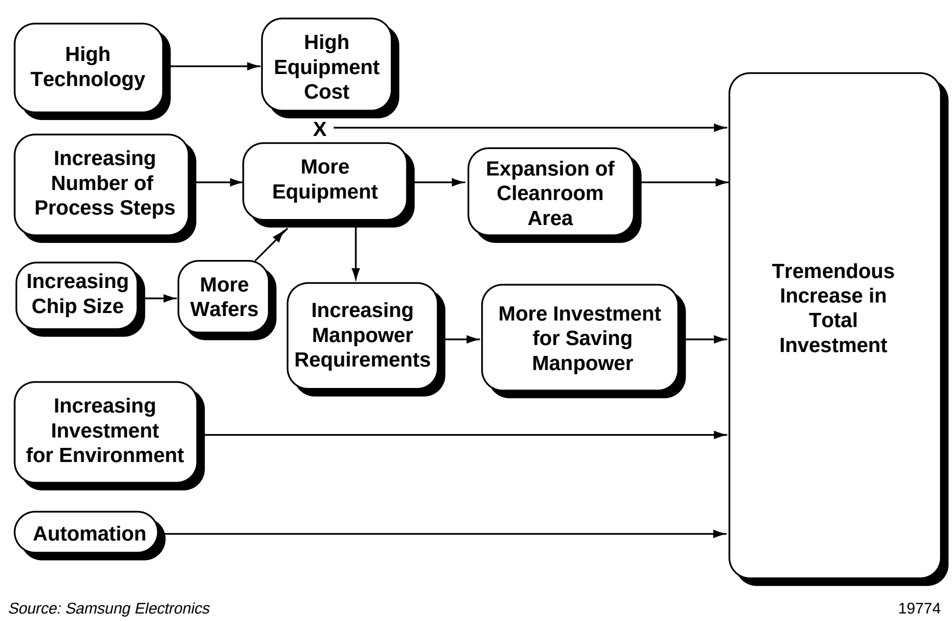


Figure 1-41. Why Total Investments is Going Up

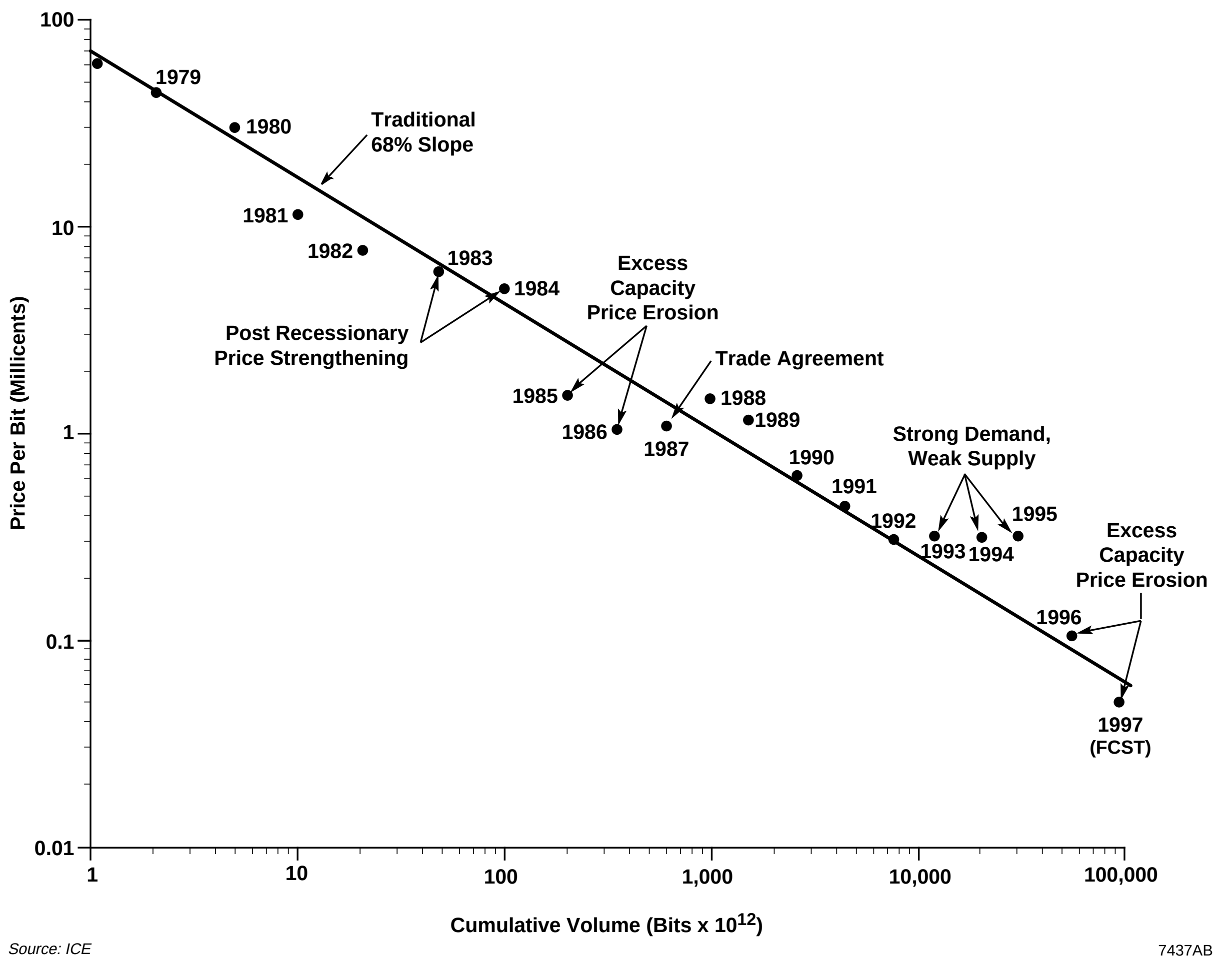


Figure 1-42. Price Curve for DRAM

In summary, manufacturing costs are escalating due to a number of factors. Specifically, each device generation (every 3 years):

- Capital equipment costs increase by 1.5X,
- Clean raw materials costs increase by 35 percent,
- Die sizes increase by 30-50 percent,
- Device complexity increases due to 30 percent reduction in design rules,
- Number of process steps increases by 25 percent, and
- Test (including in-line monitoring) costs increase by 20 percent.

IC manufacturers have typically compensated for these changes by moving to larger wafers (100 to 125, 150, and 200mm) and increasing product yields to preserve costs. Unfortunately, incremental increases in yield are rapidly being exhausted (as die yields approach 90 percent or better on some mature products). Therefore, future productivity gains, as shown in Figure 1-46, will greatly rely on improving the productivity of wafer processing equipment.

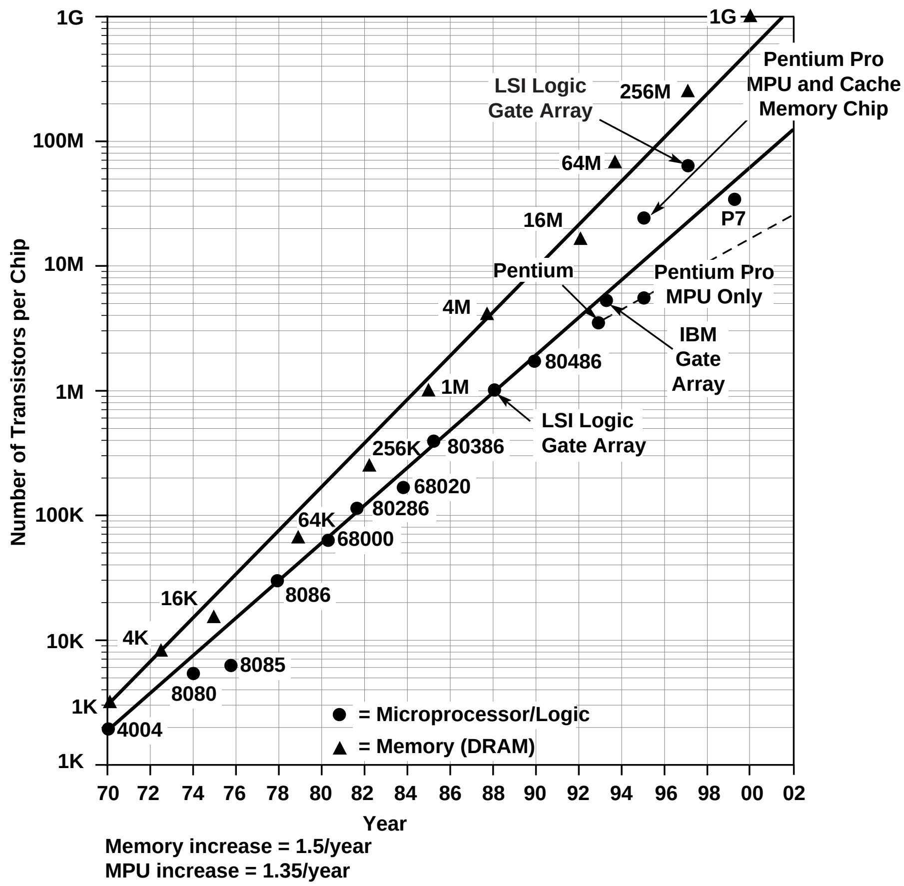


Figure 1-43. Moore's Law

Year	Microprocessor	Introductory Price (Cents/Transistor)	Introductory Price (Dollars/MIPS*)
1978	8086	1.2	480
1982	286	0.27	135
1985	386	0.11	50
1989	486	0.08	47
1993	Pentium	0.03	9
1995	Pentium Pro	0.02**	4
Average decline per year		21%	24%

*Million instructions per second
**Excluding 15M-transistor cache chip

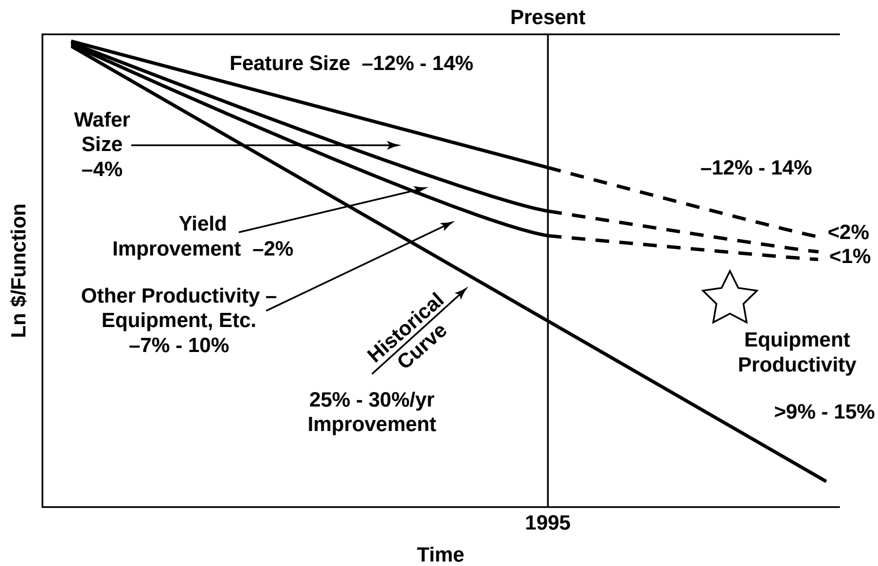
Source: ICE 19976A

Figure 1-44. Reduction in Cost Per Function for Intel's Microprocessors

Product	Mask Layers	Feature Size (µm)	Capital Investment Needed to Produce Part at Peak Volume
386	10	1.0	$200M
486	12	0.8	$1.0B
Pentium	18	0.6	$5.0B
Pentium Pro	22	0.35	$25B?

Source: Intel 18605B

Figure 1-45. Surging Capital Needs



Source: Sematech/Semiconductor International 21073

Figure 1-46. Cost Productivity Curve

Methods for assessing equipment productivity are discussed in Chapter 4 of this book, “Fab Benchmarking” and practical examples of equipment improvement programs are shown in Chapter 8, Equipment-level Cost and Productivity.”

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