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The computer, it can safely be claimed, is a revolutionary technological leap forward, a technical advance of extraordinary economic and social significance. To gauge its impact, compare it to the first "industrial" revolution described by economic historians, which transformed England during the waning decades of the eighteenth century and well into the next. The single commodity which fell most in price was cotton cloth, which plummeted at an annual rate of 3.1 percent.[1] You may protest that the first industrial revolution was at its heart a cheapening in the cost of mechanical energy which far exceeded its measurable impact on the cost of products in which it was an input. Economic historians tell us that the marginal cost of mechanical energy dropped by fifty percent over the fifty years of most rapid change.[2]

Recently, a number of studies have attempted to measure technical progress in computers, and the contrast is striking. In all of these studies, average rates of decline in real, quality-adjusted computer prices have exceeded twenty percent per year, and perhaps even exceed 25 percent per year.[3] Technological advance seems to have resulted in a continuous decline in cost for an economically significant good almost a

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[1] See D.N. McCloskey, "The Industrial Revolution, 1780-1860: A Survey," in Roderick Floud and Donald McCloskey, Ed., **The Economic History of Britain since 1700, vol. 1: 1700-1860** (Cambridge: Cambridge University Press) 1981, tables 6.1, 6.2.

[2] See G. N. Von Tunzelman, **Steam Power and British Industrialization to 1860** (Oxford: Clarendon Press), 1978, pp. 150-56. Note that the decline in the marginal cost of power exceeded the decline in average cost, due to the progressive exhaustion of sources of cheap hydroelectric power.

[3] See Kenneth Flamm, **Targeting the Computer: Government Support and International Competition**, (Washington: Brookings Institution), 1987, pp. 27-28, for references.

full order of magnitude greater than anything seen during the first great industrial revolution, and probably the longest sustained (over four decades now), steep decline in price seen in recorded economic history.

This extraordinary rate of technological progress has brought with it enormous economic impacts. Some simple approximations suggest that just one year's technological progress brings with it to industrial users of computers in the United States a social benefit equivalent to .3 to .8 percent of the GNP, a significant chunk indeed in an era to 2 to 3 percent annual growth rates.[4]

Capturing some of the economic gains from continued technological advance in computers must certainly be one of the major reasons why developing countries are today interested in learning to use and produce computer technology. But it is not the only reason. The first, staggeringly large investments in computer technology were made for military reasons, and national security objectives continue to be a major force driving developments at the leading edge of the "envelope" of computer technology, particularly in the United States.[5] While these forces may also play some role in pushing the NICs into computers, however, the main motivation seems to be economic, and it is economic aspects of the computer industry, and their implications for NICs, that will be considered in this paper.

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[4] See Flamm, **Targeting**, pp. 32-35. Large magnitudes are also derived from consumers surplus calculations for the social benefits from technological advance in computers used in the American banking industry; see Timothy F. Bresnahan, "Measuring the Spillovers from Technical Advance: Mainframe Computers in Financial Services," **American Economic Review**, vol. 76, September 1986, pp. 742-55.

[5] See Kenneth Flamm, **Creating the Computer: Government, Industry, and High Technology**, (Washington: Brookings Institution), 1988, chapter 3.

First, we shall briefly review the most significant features of the industry, as it has developed in the industrialized countries. Then we point to some recent changes that are transforming the nature of competition in this sector. Last, we draw some implications for computer-related policies in newly industrializing countries (NICs).

Key Features of the Computer Industry

Historically, computers have been characterized by a high rate of technological progress, heavy R&D intensity, and extensive involvement of government in technology development. Each of these has consequences for the structure of the industry.

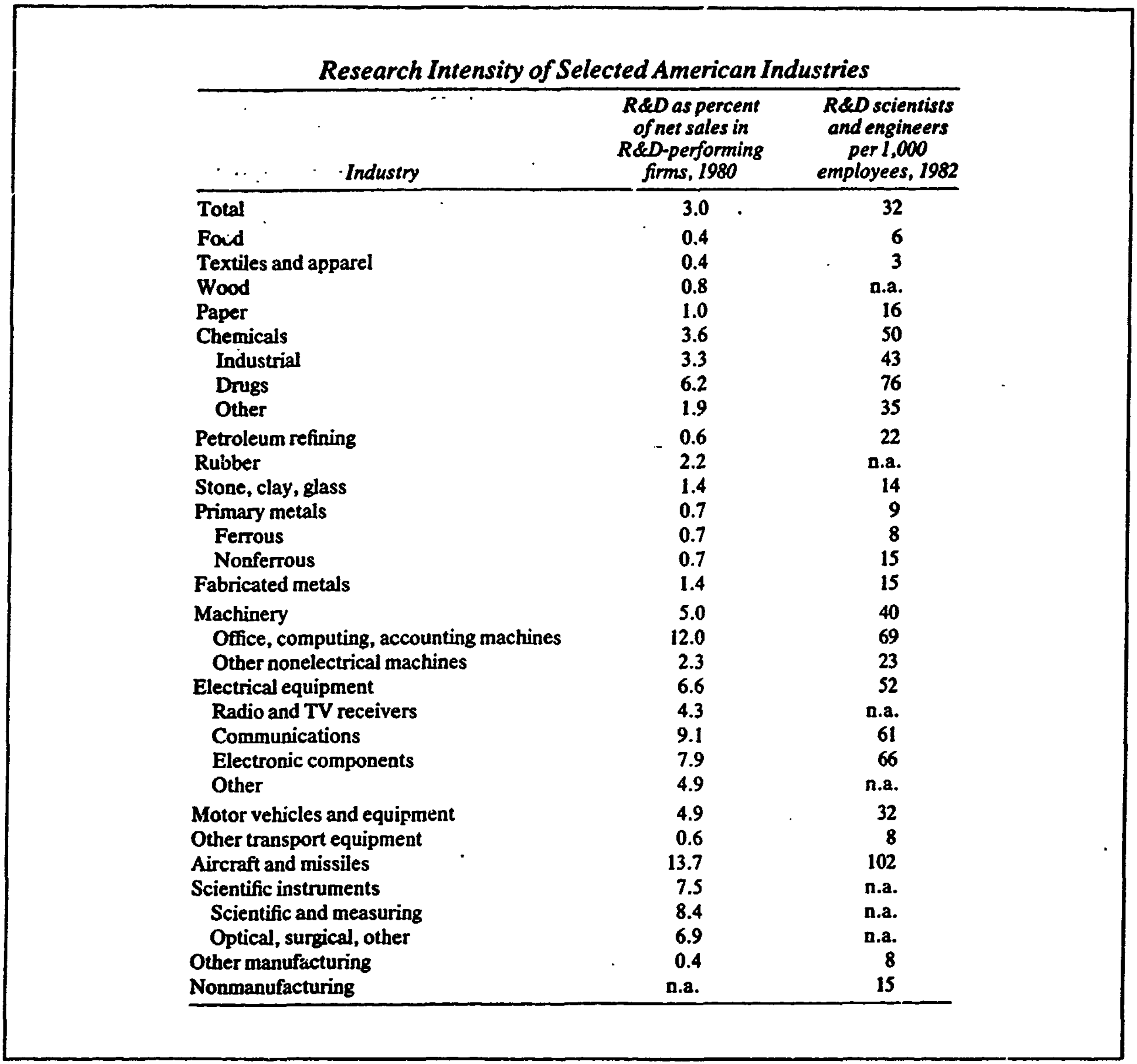
High Rate of Technological Progress. The aggregate economic significance of this technological advance has already been mentioned. But the very nature of growth and competition in this industry is also tightly linked to the extraordinarily rapid pace of innovation.

The fact that the share of computer shipments in GNP has been steadily rising-- until it today approaches 2 percent in the United States-- in the face of plummeting prices means that demand must be highly price-elastic. Indeed, the few available quantitative estimates suggest a price elasticity of demand in the -1.4 to -1.5 range, meaning that a 10 percent decline in price results in a 15 percent increase in demand for computing power if all else is equal.

For the industry, this has meant that computer demand has always been expanding by leaps and bounds, with computers penetrating into new industries and applications as the price of computing power has dropped. New niches for specialized systems, new uses for cheap computing power have constantly been opening up. Such niches have grown rapidly into huge established markets with further price declines. Targeting new niches and applications has always been, and continues to be, one of the most successful strategies for entering the computer hardware business. Most of the success stories of entry into the American industry involve some variant of this tactic: Digital Equipment pioneering the minicomputer in academic and scientific markets, Control Data and later Cray focusing on supercomputers, Apple pioneering the microcomputer. While European companies have not on the whole been particularly successful, similar pursuits of brand new markets characterize the most successful of the European firms: Nixdorf, for example, with the minicomputer, and Norsk Data introducing the high performance super-mini into European markets.

In established, mature markets, by way of contrast, large firms have tended to dominate established applications, in part because of significant economies of scale and scope. Small firms pioneering new markets have either grown large and come to dominate the maturing markets they pioneered, or have gone broke, or have been absorbed into large firms servicing those established markets. One of the main sources of those economies of scale has been the heavy technology-intensity of computer production.

Heavy R&D Intensity. If technology intensity is measured by either research and development expense as a share of sales, or R&D scientists and engineers per thousand employees, computers rank at the very top of commercially-oriented industries (see figure 1), spending 12 percent of sales and employing 69 researchers per 1000 employees. Only aircraft and missiles spend a higher share of their revenues on R&D, but this is essentially a military and defense-oriented sector. Among commercial industries, the runner-up, communications equipment, spending 9.1 percent of sales on R&D, trails substantially behind computers.



Research Intensity of Selected American Industries

Industry	*R&D as percent of net sales in R&D-performing firms, 1980*	*R&D scientists and engineers per 1,000 employees, 1982*
Total	3.0	32
Food	0.4	6
Textiles and apparel	0.4	3
Wood	0.8	n.a.
Paper	1.0	16
Chemicals	3.6	50
Industrial	3.3	43
Drugs	6.2	76
Other	1.9	35
Petroleum refining	0.6	22
Rubber	2.2	n.a.
Stone, clay, glass	1.4	14
Primary metals	0.7	9
Ferrous	0.7	8
Nonferrous	0.7	15
Fabricated metals	1.4	15
Machinery	5.0	40
Office, computing, accounting machines	12.0	69
Other nonelectrical machines	2.3	23
Electrical equipment	6.6	52
Radio and TV receivers	4.3	n.a.
Communications	9.1	61
Electronic components	7.9	66
Other	4.9	n.a.
Motor vehicles and equipment	4.9	32
Other transport equipment	0.6	8
Aircraft and missiles	13.7	102
Scientific instruments	7.5	n.a.
Scientific and measuring	8.4	n.a.
Optical, surgical, other	6.9	n.a.
Other manufacturing	0.4	8
Nonmanufacturing	n.a.	15

Figure 1 Source: Flamm, **Targeting the Computer**, p. 5.

The highly research-intensive nature of computer production has had many significant consequences for the computer industry. Perhaps the most noticeable has been important economies of scale and scope in the production of equipment drawing on the results of those R&D investments. To a first approximation, whether one produces 10 computers or 10,000 computers, the costs of developing the machine are roughly constant. Thus, the larger the sales base, the lower the average unit cost of producing computer hardware.

These economies of scale in the use of the outcomes of R&D have created an unrelenting pressure for manufacturers to seek out the widest possible market for their products, to maximize the return on their relatively fixed R&D investments. As a consequence, the industry has been unrelentingly international in focus right from the start. Major producers quickly turned to foreign markets in their quest for a larger sales base.

The relative fixity and great importance of R&D costs have also pushed computer companies to utilize the R&D in a range of different products, addressing the needs of different markets, in order to reap economies of scope. Since the mid-1960s, the concept of compatibility-- the creation of standards which allow hardware and software to be used on a variety of different computer models-- has been a major tool used by both computer producers and consumers to reduce their costs of producing and using computers. The evolution of standards and compatibility issues within the international computer industry has become the focus for a major change in patterns of competition within the industry, and this transition is discussed in greater detail below.

The interplay between industry structure and firm strategies in a technology-intensive industry have created a pattern of competition which is particularly striking in the computer industry. Historically, small firms have been disproportionately important in introducing new technologies or addressing new market niches, while larger firms have been most successful in relatively mature markets. I have argued elsewhere[6] that

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[6] See Flamm, **Creating the Computer**, chapter 7.

this complex ecology is due to what has been dubbed the "Arrow effect," not because of the arrows sticking out of the backs of pioneers, but because the argument was first made by economist Kenneth Arrow.[7] Briefly, when a firm has an unthreatened monopoly in a particular market or application, the profits from introducing a new product or process are to some extent offset by reduced profits on obsolete products or processes which are displaced. A firm with no existing product line, on the other hand, which can become a monopolist on the strength of a significant new technology, has no existing product line to write off, and thus earns a greater private return on the same technology investment.

The historical introduction of the microcomputer is a probably a tolerably good approximation to the Arrow effect in action. When start-up Apple brought out the Apple II in 1977, it had no existing product lines threatened by rising sales of its new computers. IBM did not react and introduce the IBM PC until late 1981, and the impact on its sales tells much of the story on the reasons for its slow response. In a period of vigorously growing demand for computers, its PC sales shot up like a rocket: its micro revenues grew by $2.1 billion between 1982 and 1983. However, this was offset by absolute **declines** of $400 million in office systems and $200 million in minicomputers over the same period. Apple had no such offsetting losses when it brought out its new product.

Thus, older incumbent firms dominating mature markets have good economic reasons for moving more conservatively in bringing out new technology, while young start-ups can achieve greater returns from the same innovations. Historically, many new computer start-ups have originated with engineers and technical people from

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[7] This has also been called the "replacement effect". See Jean Tirole, **The Theory of Industrial Organization**, (Cambridge: MIT Press) 1988, p. 392.

established firms, disgruntled with the slow pace at which the new technology they worked on was introduced, leaving the established company and striking out on their own to bring the technology to market. From this perspective, large, established firms and new start-ups play different social roles in a complex industrial ecology. The large incumbent firms reap economies of scale and scope in established markets, the small start-ups pioneer new markets and technologies, then grow into large firms as the markets mature, or die, or get absorbed into large firms.

If one accepts this view, recent discussions suggesting that either established, large, integrated firms, or small, entrepeneuerial start-ups are somehow better than the other (and therefore that the other form of industrial organization is to be avoided and to blame for competitive problems in the electronics industry) are misguided.[8] Big and small firms are neither "good" nor "bad," per se, but serve different functions within the industry, coexisting in a symbiotic relationship.

Finally, the heavy research intensity of the computer industry goes hand-in-hand with continued extensive involvement by governments in the industry. For a variety of reasons-- particularly the inability of private firms to appropriate, to capture, the results of the most fundamental and radical sorts of R&D projects for their exclusive use, economists argue that social returns to R&D generally exceed private gains. This has created a logic pushing government involvement in the industry, particularly in investments in the technology base.

Government's Role in Computers. Government involvement in computer technology was originally motivated by national security objectives. But in the late

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[8] This is exemplified, for example, in the 1988 debate between George Gilder and Charles Ferguson carried on in the pages of the **Harvard Business Review**.

1950s, and early 1960s, as the growing economic consequences of the technology became apparent, government initiatives in computers motivated by a desire to capture economic returns-- particularly in Europe and Japan-- took shape. These efforts encompassed the creation of trade barriers around the domestic market, in order to provide a sheltered national market, and subsidies to technology investments. In Europe, the sheltered national market was handed over to "national champion" firms, essentially conceived as national scale models of IBM. These protected national champions never really emerged from their sheltered niche into the international marketplace, and these policies (followed to a greater or lesser extent in Britain, France, and Germany) are now widely acknowledged to have been failures.

In Japan, on the other hand, competition among Japanese firms was encouraged within the national market, and emphasis given to exports and the production of internationally competitive products. In the 1970s, formal barriers to computer imports were removed. Technology subsidies were organized through cooperative joint research projects. Today, Japanese firms are serious challengers to the traditional hegemony of American computer companies in the world market, and those policies must be viewed as a successful response to the conditions of the time. However, the computer industry is moving through a period of transition, and it is not clear that the formulas of the 1960s and 1970s are appropriate for the 1990s.

In the United States, military programs continue to be the primary vehicle for government investments in computer technology. But it is not clear that this continues to be a particularly effective way to invest in the commercial technology base in the world of technological peers and competitors that America entered in the 1980s, and a debate over how to restructure those investments in order to increase commercial relevance has moved to center stage in the United States.[9]

The bottom line is that government plays a central role in investments in computer technology around the world. In the United States, in the early 1980s, government paid for perhaps 2/3 to 3/4 of basic research in the area, 40 percent of all research, and perhaps 20 percent of research and development.[10] These numbers reinforce the point that government is most important in funding the least appropriable, most basic sorts of investments, while private industry dominates the development of commercial products building on that technology base (80 to 85 percent of R&D performed by American companies is development, not research; only 1.5 to 2 percent of industrial computer R&D is basic research).

The practical significance of the ubiquitous role of government in technology investments is that such involvement is one of the rules of the game, everywhere. It is so pervasive that it is not controversial. Where opinions diverge, and where political pressures play a role in circumscribing policy options, is in the erection of barriers to trade and investment around national markets. This issue is particularly tricky in the computer industry, since every firm that is a significant player in the industry has a major presence in international markets. Because it is difficult to become a competitive force in the industry without access to the international marketplace (and the technologies and competitive pressures that foreign producers bring with them when they enter the national market), and increasingly hard to gain access to foreign markets without in turn opening one's domestic market, strong pressures to permit some sort

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[9] For one view of this debate, see Kenneth Flamm and Thomas M. McNaugher, "Rationalizing Technology Investments," in John Steinbruner, Ed., **Restructuring American Foreign Policy**, (Washington: Brookings Institution) 1988.

[10] See Flamm, **Targeting the Computer**, pp. 104-105.

of access by foreign computer companies to the national market inevitably work against even the most determinedly protectionist policies.

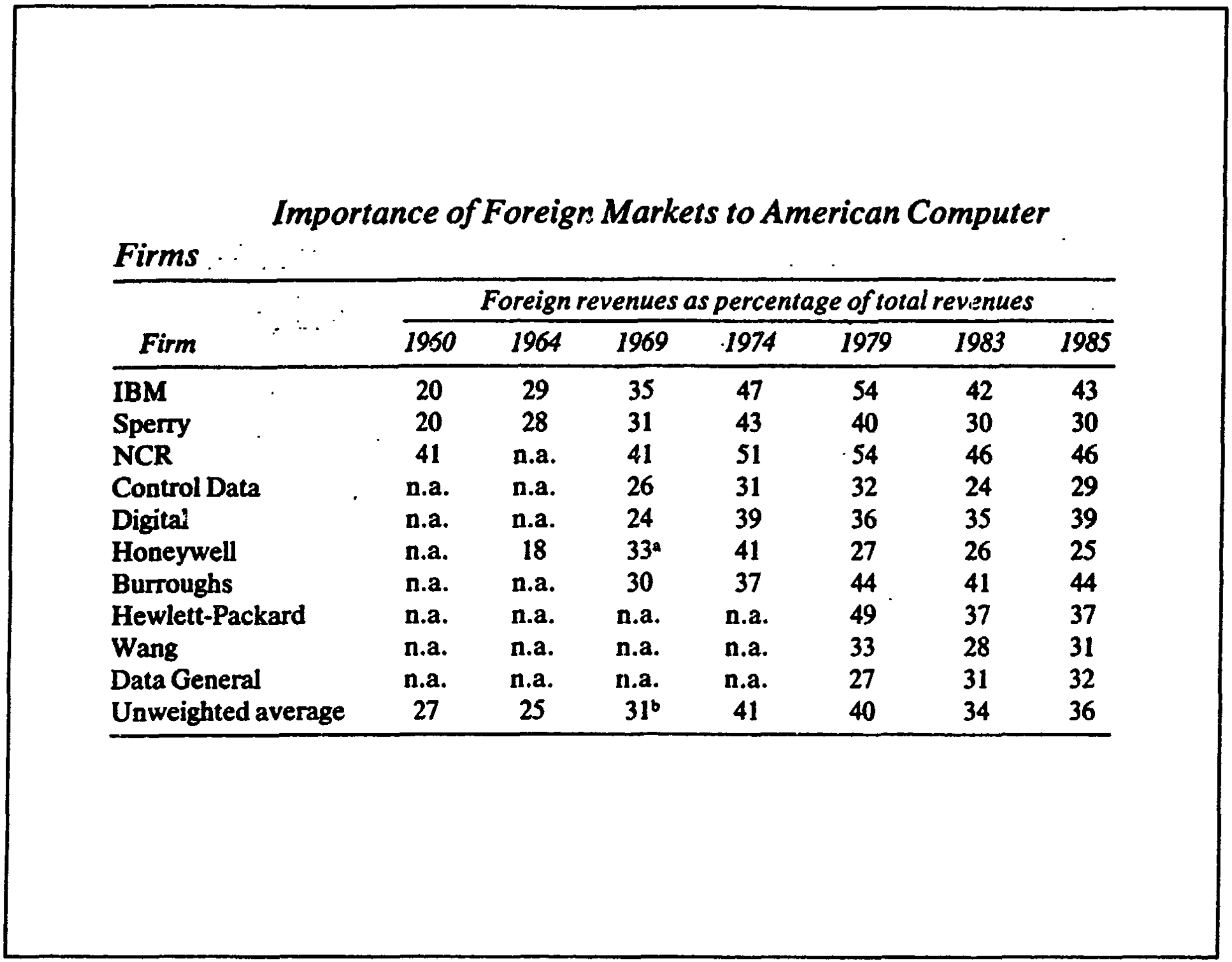
Recent Trends

While the phenomena described above have been felt throughout the history of the computer industry, the unceasing change, ferment, and turmoil produced by these elements has been an equally constant feature of the industry. As we enter the 1990s, one can trace out some of the most important changes shaping what will clearly be a new and different industry structure.

Continued Internationalization. The main consequence of the relative fixity of R&D costs for the structure of the industry has been a constant expansion into the international marketplace. Figure 2 shows the trend for U.S. computer companies. In recent years, foreign sales have typically accounted for 40 to 50 percent of the revenues of American computer companies.

To be successful in the computer business, companies have had to reach out to the global market. With no exceptions, world-class firms have eventually had to produce products competitive in the international marketplace. An inward-looking strategy-- taking shelter behind trade barriers in a protected national market-- has never proven successful in the long run.

Because governments' historical interest in computers has been longstanding and intense, and national policies have frequently encouraged the domestic production and manufacture of computers, the quest for international markets has frequently led to direct investment in a foreign subsidiary, rather than export sales. This is clearly



Importance of Foreign Markets to American Computer Firms

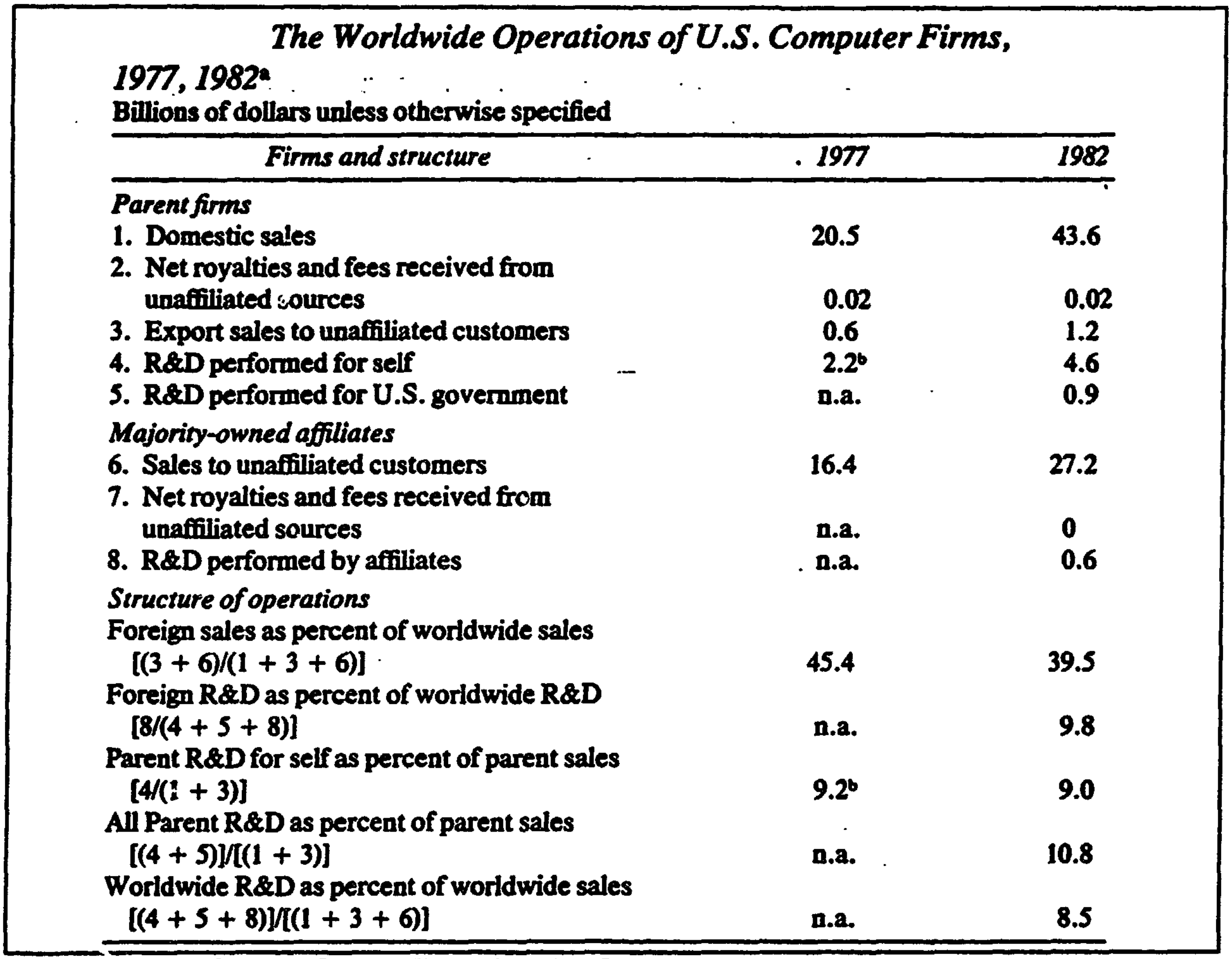
	Foreign revenues as percentage of total revenues						
Firm	*1960*	*1964*	*1969*	*1974*	*1979*	*1983*	*1985*
IBM	20	29	35	47	54	42	43
Sperry	20	28	31	43	40	30	30
NCR	41	n.a.	41	51	54	46	46
Control Data	n.a.	n.a.	26	31	32	24	29
Digital	n.a.	n.a.	24	39	36	35	39
Honeywell	n.a.	18	33[a]	41	27	26	25
Burroughs	n.a.	n.a.	30	37	44	41	44
Hewlett-Packard	n.a.	n.a.	n.a.	n.a.	49	37	37
Wang	n.a.	n.a.	n.a.	n.a.	33	28	31
Data General	n.a.	n.a.	n.a.	n.a.	27	31	32
Unweighted average	27	25	31[b]	41	40	34	36

Figure 2 Source: Flamm, **Creating the Computer**, p. 101.

reflected in available statistics on the revenues of American computer multinationals (see figure 3). In 1982, exports by American computer firms to unaffiliated foreign customers were less than $1.2 billion, compared to $43.6 billion in domestic sales. Despite the high dollar that year, foreign subsidiary sales weighed in at $27.2 billion, or forty percent of worldwide sales. That share is certainly much higher today, with the much weaker dollar.

The portrait painted by figure 3 also shows that royalties and fees on sales of technology to unaffiliated domestic and foreign customers brought in less than .03

percent of revenues from product sales. Clearly, formal sales of computer technology through licensing agreements are an insignificant avenue of technology transfer. Computer companies (excluding perhaps those facing impending financial disaster) are exceedingly reluctant to sell rights to their mainstream technologies at arms length, and on those rare occasions when they do, it is typically older vintage technology that has been rendered obsolete by more recent innovations.



The Worldwide Operations of U.S. Computer Firms, 1977, 1982[a]

Billions of dollars unless otherwise specified

Firms and structure	*1977*	*1982*
Parent firms		
1. Domestic sales	20.5	43.6
2. Net royalties and fees received from unaffiliated sources	0.02	0.02
3. Export sales to unaffiliated customers	0.6	1.2
4. R&D performed for self	2.2[b]	4.6
5. R&D performed for U.S. government	n.a.	0.9
Majority-owned affiliates		
6. Sales to unaffiliated customers	16.4	27.2
7. Net royalties and fees received from unaffiliated sources	n.a.	0
8. R&D performed by affiliates	n.a.	0.6
Structure of operations		
Foreign sales as percent of worldwide sales [(3 + 6)/(1 + 3 + 6)]	45.4	39.5
Foreign R&D as percent of worldwide R&D [8/(4 + 5 + 8)]	n.a.	9.8
Parent R&D for self as percent of parent sales [4/(1 + 3)]	9.2[b]	9.0
All Parent R&D as percent of parent sales [(4 + 5)]/[(1 + 3)]	n.a.	10.8
Worldwide R&D as percent of worldwide sales [(4 + 5 + 8)]/[(1 + 3 + 6)]	n.a.	8.5

Figure 3 Source: Flamm, Targeting the Computer, p. 11.

n.a. Not available.

a. Data refer to nonbank U.S. parent firms in the office, computing, and accounting machines industry and their majority-owned nonbank affiliates.

b. R&D expenditures for parent's own benefit whether or not performed by parent.

Instead, people seem to be the most important medium of technology transfer. The movement of trained people from research labs to industry, and from company to company, tracks the birth of new computer companies, new markets, and new technologies. In computers, as in semiconductors, an inverted "tree" is a reasonable approximation of relationships between companies and technologies over time.

The internationalization of the industry has moved hand-in-hand with the internationalization of the technology. Within a multinational computer firm, people and know-how flow across national boundaries in the pursuit of its economic self-interest. The local subsidiaries of multinational computer companies, particularly in large, industrialized countries, have to some extent transferred computer technology through the training of local employees, who take their knowledge with them when they move on to another employer. Conversely, the firm will seek out new technology and ideas wherever they are found, and attempt to tap into them. At the international level, firms have realized that local R&D laboratories and subsidiaries can tap into national research communities around the globe. Figure 3 shows that R&D performed by foreign affiliates of American computer multinationals accounted for about 10 percent of worldwide R&D in 1982.

The Drive Toward Standards. The relative fixity of R&D cost has also meant that producing a wide range of products drawing on the underlying R&D base has served to increase the returns to that R&D investments. One way to increase such economies of scope in the utilization of R&D has been to define **standards** for computer hardware and software, which allow products developed for one system design to perform with others as well. Quite apart from the economies standardization creates in the production of new products, and consequent declines in cost, standards bring additional benefits to users of computer products. Since users typically make large investments in learning how to use computer systems, standards may mean substantial cost savings when they run many distinct applications on the computers they use. And since computer users typically want to share information with other computer users, use of standards allows them to communicate more cheaply, to enjoy so-called network externalities.

The benefits of standardization are traded off against the performance gains that specialization can bring in a single application. That is one reason why pioneering a new market or application has often been a successful strategy for a newcomer to enter the computer hardware business, despite the economies of scale and scope that an established firm, with a large installed base, enjoys in a relatively mature application. An application requires both hardware and software. In an existing, mature application, a new and incompatible machine with superior price-performance will require new software as well, while an older machine which makes use of existing software requires no new software investment. The total systems cost with the new hardware, therefore, will typically exceed that with the older, inferior hardware, despite a substantial gain in hardware price-performance. In a new application, however, new software investment is inevitable no matter which hardware is used, and a substantial price-performance advantage for the new hardware can much more readily be translated into a decrease in total system cost.

The benefits of standards were learned by trial-and-error during the historical evolution of the industry, and changes in the standardization strategies of firms have often marked periods of transition and consolidation in the industry. The early days of the industry, in the 1950s, were dominated by the attempts of firms to take the infant technology and apply it to particular market and applications niches. The first mammoth computers (built with government funds) were adapted to scientific and business needs, with large and small models targeting particular kinds of applications. As the technology was differentiated, models proliferated. By the early 1960s, a virtual Babel of computers existed, with different models manufactured by a single producer often requiring totally different kinds of peripherals and software.

In the mid-1960s, IBM introduced its System 360 computer line, which was to transform the industry. For the first time, a whole range of hardware models used a common set of peripherals and software. Users quickly learned to appreciate the cost benefits of standardization, and IBM's initial lead in the computer marketplace was cemented firmly into place. Other producers of mainframes eventually reacted by consolidating their many models into a single architectural family, but by the time this had happened, IBM had a huge lead in installed base. The late 1960s and early 1970s saw many of IBM's strongest and most substantial rivals exit from the mainframe computer business.

One of those competitors, RCA, appreciated the significance of IBM's innovation, and introduced a family of computers designed to tap into IBM's installed base, a series of computers with some degree of compatibility with the IBM standard. But RCA's adherence to the standard was incomplete: IBM software generally had to be modified to run on the RCA machines, and IBM peripherals could not be attached. RCA's effort flopped, and it quit the computer business.

But the idea of producing IBM-compatible hardware lived on, and in the late 1960s and early 1970s, a number of companies began to produce computers and peripherals that were "plug-compatible" with IBM equipment. The most successful were two Japanese companies, Hitachi-- whose computer designs had initially been licensed from RCA while RCA was still on the scene-- and Fujitsu-- which became the largest single shareholder in Amdahl, a new venture in IBM plug-compatible computers started up by Gene Amdahl, formerly one of IBM's top system designers. Hitachi and IBM were to prove relatively successful with this strategy, largely on the basis of large investments in state-of-the-art semiconductor technology used to maintain a price-performance edge over IBM equipment using less advanced semiconductors. But it was a difficult strategy to follow, since IBM was free to change its standards at will, and confound its would-be imitators. IBM could and did do precisely that.

IBM's freedom to change its proprietary standard at will, coupled with aggressive legal maneuvers by IBM to assert control over its architecture, made it more and more difficult for the Japanese plug compatible manufacturers to make a profit in the IBM mainframe market. In the 1980s these firms, and others, were to increasingly favor a new strategy that began to take shape, marketing products that conformed to non-proprietary industry standards.

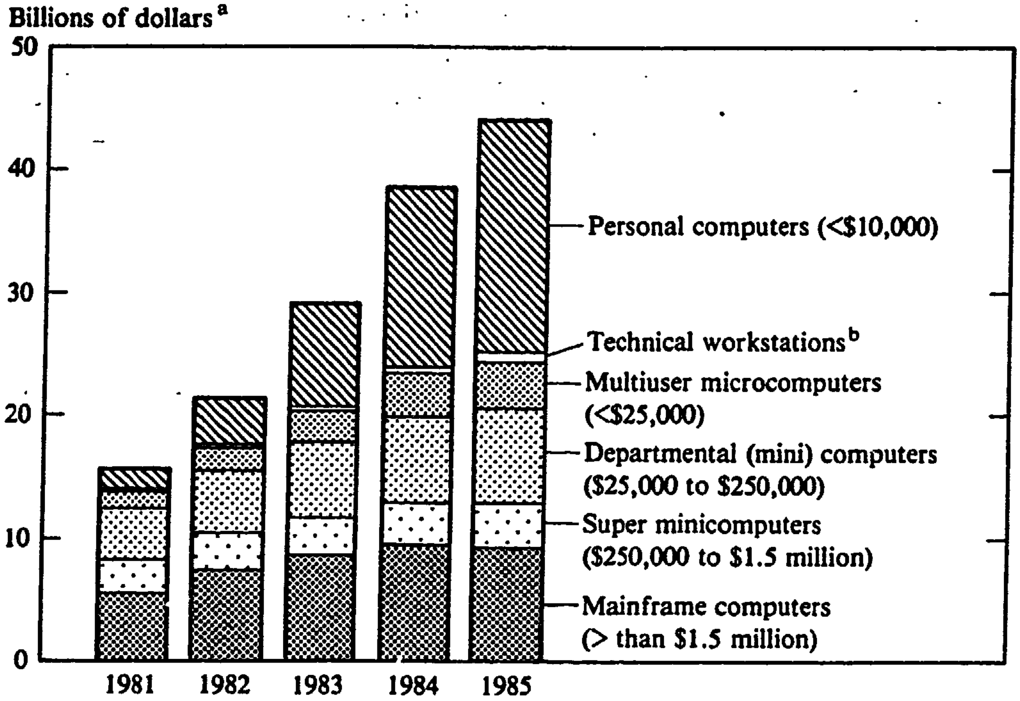
The germ of this new strategy was formed in the early 1970s, when researchers at AT&T's Bell Telephone Laboratories designed a new operating system, UNIX, with the aim of porting it easily from one type of hardware to another. UNIX was distributed freely to researchers at American universities, who modified and improved the original AT&T code. Soon, variants of UNIX were running on high performance minicomputers that were appearing in large numbers at universities. Eventually, the University of California at Berkeley started a project-- funded by the military-- to incorporate advanced network features into UNIX, so computers running the system could easily communicate with the ARPANET, the military's pioneering packet-switched, wide area computer network.

Other fledgling computer companies soon realized that by supporting UNIX on their new products, they could tap into a large and growing university and defense computer base, a market that in any event would be among the most likely targets for new, advanced, high performance hardware. The Europeans, faced with the collapse of their "national champion" strategies, became interested in UNIX as a vehicle for combining their relatively small user bases into an aggregate that could at least begin to approach the economic advantages of the enormous IBM user base. Standards organizations were formed to settle on a single European UNIX, and were joined by American sympathizers. And the Japanese, constantly running to catch up with IBM after its latest strategic change in its standards, under attack on intellectual property issues by an army of IBM lawyers, also began to seriously think about switching over to UNIX. And the also-ran American mainframe computer companies, companies like Burroughs, Sperry (later to merge with Burroughs into Unisys), NCR, Honeywell, even supercomputer producer Cray, also began to introduce products supporting UNIX. Even the United States government was to lend its imprimatur to the trend, by specifying UNIX-like specifications for much of its computer procurement.

By the mid-1980s, UNIX was firmly established as an alternative to proprietary standards, and rapidly gaining ground. The emergence of a non-proprietary, international industry standard operating system coincided with the creation of another set of de facto non-proprietary hardware and software standards, those associated with the IBM personal computer.

The decision by IBM to put its PC standard into the public domain was a tactical move, designed to overcome its late entry into the PC market. That decision turned out to have great strategic consequences. Competitors were free to produce IBM-compatible PC hardware using industry-standard parts, with relatively low R&D costs. Exceedingly attractive price-performance made PCs turned out by a highly competitive

Values of Computers Shipped to the U.S. Market



Source: Unpublished data from Dataquest Inc., San Jose, Calif., cited in U.S. Bureau of the Census, *Statistical Abstract of the United States, 1987* (Government Printing Office, 1986), p. 747.

[a] Statistics depicted in figure 8-1 differ from those in figure 8-2 because of differences in categorizing computers, as well as differences in the extent to which peripheral equipment incorporated into a system is counted.

[b] Excluding computer-aided design and manufacturing systems shipped by original equipment manufacturers.

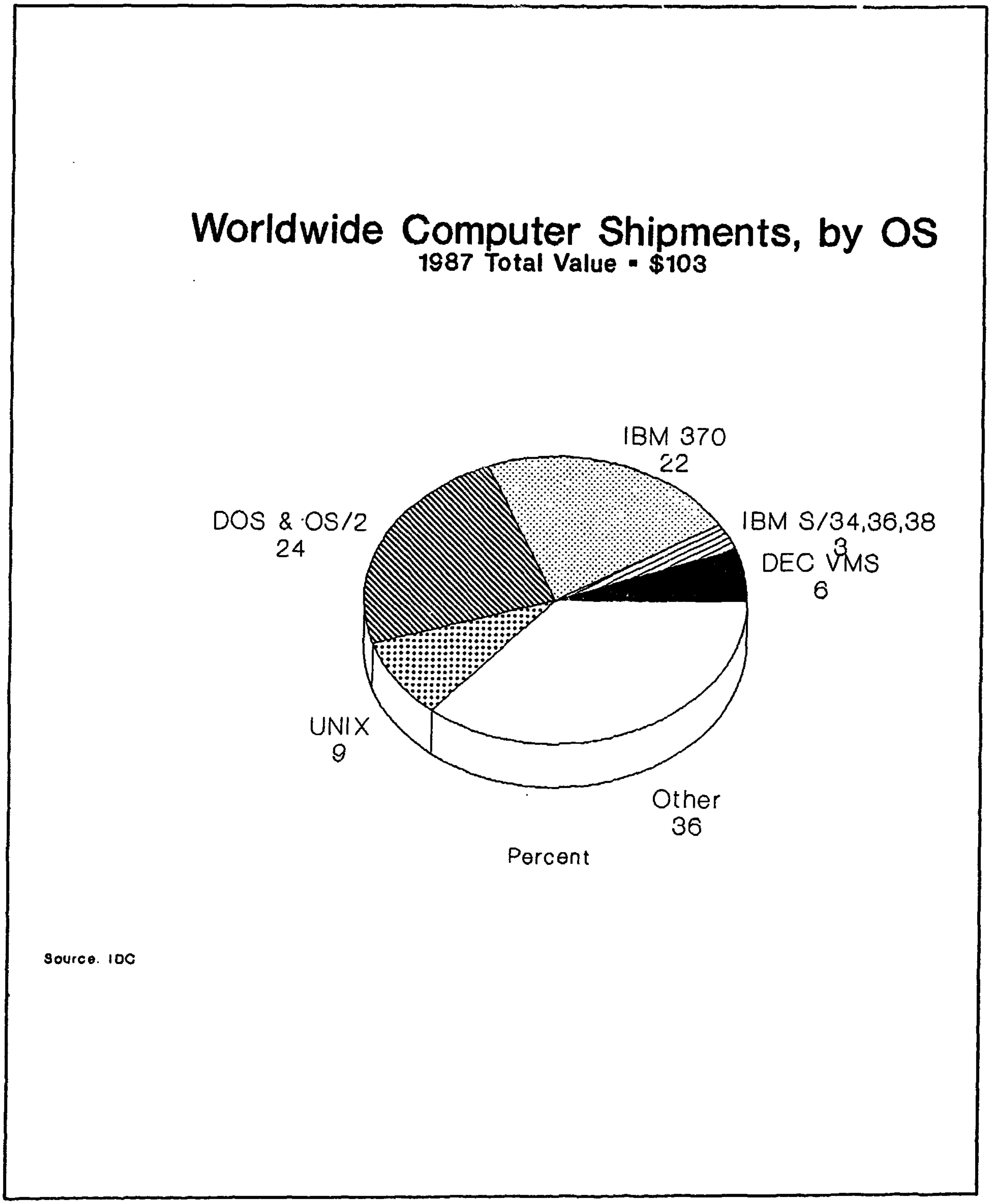
Figure 4

industry instant winners with computer users. PC shipments rose sharply, and today, desktop systems account for about half of American computer sales (see figure 4). The IBM PC standard and its associated operating systems (MS-DOS, and its successor OS/2, licensed by software producer Microsoft to all comers at reasonable rates) constitute a de facto international, non-proprietary standards.

Today, more computer dollars are spent by installations using non-proprietary standards UNIX and MS-DOS-OS/2 than are expended by users using the principle proprietary standards, IBM mainframe and mini operating systems and Digital Equipment's VMS operating system (see figure 5). Furthermore, many manufacturers shipping computers using operating systems falling in the "other" category are committed to supporting UNIX, and much of that pie slice will surely be joined to UNIX in coming years.

This movement toward non-proprietary international standards is reshaping the nature of industrial competition in computers. It is best understand as a floating crap game of governments and corporations formed into shifting, rivalrous coalitions, maneuvering for what they perceive to be their self interest. Even IBM and Digital are under pressure to support the UNIX standards, and their role in a recent schism in the UNIX world-- promoting the formation of another competing standards organization attempting to define the UNIX standard-- is portrayed by some as a complex strategem to make their proprietary standards look more attractive. In any event, the computer industry is making a transition to a brave new world where non-proprietary international standards will be a force shaping competition, and the structure of that new environment is not yet entirely clear.

The Rise of Intellectual Property Issues. Another recent development of great



Source. IDC

Figure 5

significance to developing countries has been the rise of intellectual property issues as a significant factor in competition between firms. In the early days, when the computer industry was basically an American enterprise, patent and copyright issues played little role. This was due to the government-funded roots of the technology, which made it difficult for private firms to assert title to concepts, to disputes among researchers which had been settled with all involved renouncing title to basic concepts, and the incremental, marginal nature of technical innovation in highly complex systems (as in electronics in general), which had made claims to title and priority difficult to settle. And settlements of government antitrust cases against IBM and AT&T made it much easier for competitors to use technologies developed by these companies. Patents were relegated to a secondary role, largely serving as bargaining chips used in cross-licensing arrangements.

This began to change in the late 1970s. IBM began to copyright its operating system software, and pursued industrial espionage and patent infringement cases against Japanese producers of plug-compatible systems. In the 1980s, cases seeking to establish legal rights to the "look and feel" of a software interface were brought before the American courts. New legislation enabled chip makers to copyright their chip designs. Texas Instruments appealed to the International Trade Commission to block the importation of dynamic random access memory (DRAM) chips infringing on its patents. The latter threat proved successful, and foreign producers negotiated substantial settlements with TI.[11]

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[11] The sums involved were quite large. For example, in 1987, TI's pretax profits on its semiconductor business were $346 million, compared to royalty income resulting from its DRAM litigation of $191 million. In 1988, TI made pretax profits of $424 million on semiconductor sales, compared with $124 million on DRAM royalties. See "TI to Cut Workforce; CPUs Double Losses," **Electronic News**, January 30, 1988, p. 37.

Whether the increasing visibility of intellectual property issues signals a major change in the rules of the game, or a temporary offensive that ultimately will fizzle, remains to be determined. It is clear, however, that the appearance of significant international competition in computers has much to do with the change in the rules. In earlier decades, the relative laxity of the intellectual property regime was irrelevant from the standpoint of the American national interest. Whether one company or another won the battle, the winner was almost certainly going to be a U.S. enterprise. And a certain looseness about intellectual property may even have contributed to the rapid diffusion of technology within the United States, and the free-wheeling, entrepreneurial style of the times.

Today, however, it is a much different story. Struggles over property rights to innovations reflect not just a distributional struggle between different American interests, but the capture or loss of rents for the national economy. And it is significant that the major victories have come before the International Trade Commission, a fundamentally political body whose deliberations only affect foreign competitors exporting to the United States. Disputes with other American companies are settled in the Patent Court, in proceedings of a much more protracted and inconclusive nature. The issue of whether or not this is compatible with the GATT framework governing international trade has yet to be settled, and the disposition of this issue will have much to do with whether a fundamentally new sort of regime gets established.

Strategic Alliances. The shift toward international standards within the computer industry in the 1980s-- with rival firms cooperating on standards initiatives-- coincided with a dramatic rise in other forms of cooperation, particularly international joint ventures and other forms of alliances among firms. Most of these alliances can be classified into one of three categories: joint research and development efforts, ventures designed to integrate new types of systems based on distinct pieces of technology contributed to the joint effort by the cooperating firms, and marketing agreements.

The first two classes of alliance address the potential for the realization of economies of scale and scope in research and development. Joint development projects allow firms to share the costs of R&D required to produce new products. Similarly, firms can combine their proprietary technologies and produce new types of systems at a fraction of the cost and risk that each would separately incur if it attempted to develop the entire system on its own. International tie-ups often avoid some of the domestic antitrust complications that might otherwise arise. And since firms of different nationalities often have marketing networks that emphasize different geographic regions, conflicts that might arise with domestic partners are minimized.

The latter consideration is a major motivation for international tie-ups to market computer products. Also, because computer markets are often surrounded by significant barriers, formal and informal, to foreign vendors, joint ventures are an attractive option for penetrating these markets. The joint venture takes on a national character that enables it to receive preferential treatment in the home markets of all participants.

Implications for Newly Industrializing Countries

The vision of competition in computer systems sketched out above leads to some concrete suggestions for policy in a country just entering the game. If one accepts the basic logic, five reasonably simple principles for policy may be suggested.

Maximize applications of computers. The enormous economic benefits of computer use described earlier are due to steep declines in computer price-performance being passed on to computer users. The improvement that new technology brings, of course, is not all immediately transferred to users. For some period of time, the innovator earns a profit-- a "technological rent"-- that provides a return on the initial investment in R&D. But given the actual behavior of computer prices over time, this must be quite small. Some indicative calculations suggest that only a small portion of the social return-- perhaps 10 to 20 percent-- is actually captured by the innovator.[12] The remainder is immediately "competed away" and passed on directly to the computer user.

Thus, the most productive task for a nation's computer policy is to put computers to work and collect those social returns. That means maximizing use and applications of computers.

As remarked earlier, however, computer use is highly sensitive to computer price, with a price elasticity in the neighborhood of -1.5. This means that policies which raise computer prices can greatly reduce computer use, and the blunt the increase in productivity that might otherwise be realized. In particular, protectionist policies which attempt to foster the domestic production of hardware will do so at the cost of significant reductions in the extent of application of computers in the national economy. A high price elasticity means that policies that raise cost will greatly blunt the economic benefits-- for example, with a constant price elasticity of demand of -1.5, a policy that doubles computer price will reduce computer use by 2/3! Policy makers should be aware of the substantial welfare costs that such cost-increasing sectoral policies will bring.

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[12] See Flamm, **Targeting the Computer**, p. 38.

Choose a viable strategy in hardware. The heavy R&D investments traditionally required to enter the computer business, and the economies of scale and scope that established producers enjoy in mature markets, make it difficult for a newcomer to break into the marketplace. The most successful, tried-and-true formula for entry, historically, has been to introduce a product targeting a new and growing niche market or application. For a developing country, this probably means choosing an application or niche where special problems or special expertise or experience gives national companies a special edge. Such applications might include cheap water control systems for rural irrigation applications, for example, or rugged and environmentally-hardened systems built to tolerate dust and power glitches.

At the lower end of the product spectrum, the growing significance of nonproprietary standards means that it is now possible to build a simple "commodity" computer using standardized components and a well-defined standard architecture, with little or no R&D investment. Given some intermediate level of engineering and manufacturing know-how, and access to components, one can build such a system. Firms competing in these "commodity" computer markets largely face the problems of a mature manufacturing industry, where relative input prices and factor productivity determine the competitive performance of a producer in world markets. For a newly industrializing country with well-honed mass production manufacturing skills, production of these commodity computer products is an entry path into the computer business.

Non-proprietary standards also mean that it is possible to specialize in the design and production of a particular subsystem, which can then be integrated into a computer system conforming to the industry standard, without mastering all the details needed to construct the entire system. A manufacturer can build modems, or memory boards, or communications software, or special hardware to accelerate scientific calculations without investing great effort in developing the innards of the systems to which these components are to be interfaced. The huge R&D investment traditionally required to enter the computer business is thus much reduced if a firm focuses on the design of a component conforming to the industry standard.

The increasing ubiquity of strategic alliances makes it more likely that relationships can be forged which improve further the chances for the both the "commodity" and "subsystem" strategies to work. If a partner company in a large industrialized country market can offer the marketing and service network that NIC company lacks, the chances that the product will be a success are further improved.

Software and systems integration. As the price of computer hardware has continued to drop, the share in total systems cost of providing software and configuring the system has risen. In part this is because software production has resisted intensive automation, and remains a highly labor (albeit skilled labor) intensive activity. NICs with large pools of labor with appropriate training in these skills have an excellent opportunity to break into the computer business through this route, at relatively little cost.

Indeed, the most profitable activities within computer companies are not selling the hardware, but instead providing software, providing maintenance, and putting together turnkey system "solutions" for computer users' needs. A NIC interested in receiving technological rents from computer systems production might choose to invest in the technological expertise required to undertake these highly profitable activities.

Export or die. It bears repeating again that the relative fixity of R&D costs makes the computer business relentlessly international in scope. The increasing internationalization of the technology also means that a company has to maintain an international presence, around the world, to stay at the leading edge. And historically, no company has ever been able to survive over the long term based only on its position in a sheltered national market.

In the long run, a successful computer company has to sell in foreign markets. For a newly industrializing country, this means policies to foster an industry ultimately must make it competitive with foreign competitors, and therefore probably require that it be forced into some degree of competition with foreign competitors in the domestic market. It also means that access to industrialized country markets is essential in the long run, and that deals may have to be cut on other issues-- like strengthened protection for intellectual property-- which in themselves may be unappealing, but are the price of admission to developed country markets.

People as the key to technology transfer. Perhaps the most important point emerging from the history of the computer industry is the central role that people play in transferring and disseminating technology. The key to gaining access to computer technology is getting your people on the inside of organizations and institutions with demonstrated capability and expertise.

Trained people are required to take advantage of such opportunities, of course, and investment in educating and training a skilled technical workforce is a prerequisite for such a strategy to work. Investment in technical and educational infrastructure is crucial. Sending people overseas for postgraduate training is a relatively cheap way of both investing in skills, and in gaining access to the computer technology that can be absorbed within a good university computer science or electrical engineering program.

If nationals can then work within high technology companies in places like Silicon Valley, before returning home, it may be possible to absorb even more relevant technology and bring it home.

Similarly, if the local subsidiaries of multinational computer companies can be induced to undertake relatively high technology activities, and train local employees in relevant skills, those local employees can be the conduit of significant technology transfer if they later leave, and migrate to a local enterprise or start up their own firm. A newly industrializing country may be able to use access to the local market as a bargaining chip to be exchanged for technologically significant activities by a multinational's local subsidiary. However, because computer companies are frequently leery of bringing their best technology into joint ventures where they have minority ownership, restrictions on majority-owned direct foreign investments-- as are frequently found in many developing countries-- may have to be waived or amended to make this tactic work.

Just ensuring that nationals are working in foreign high technology companies overseas, or studying overseas, or even working in local subsidiaries of high tech multinationals, does not ensure that technology transfer will follow. Gaining access to new technology by getting someone inside then requires that they leave and join you on the outside. Incentives may be required to ensure that trained scientists and engineers will ultimately be willing to leave the intellectual stimulation and employment security found in a top industrial R&D facility, and somehow start a local industry from scratch. Some sort of government-venture capital funding may serve both as an incentive for nationals to return, and as a mechanism to invest resources in national technical capacity.

The transition and change visible in the computer industry today promise to make it a much more competitive enterprise. The challenge for the newly industrializing countries is to put in place policies which allow them to participate in the benefits of the increasing ubiquity and declining cost of computer power.

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