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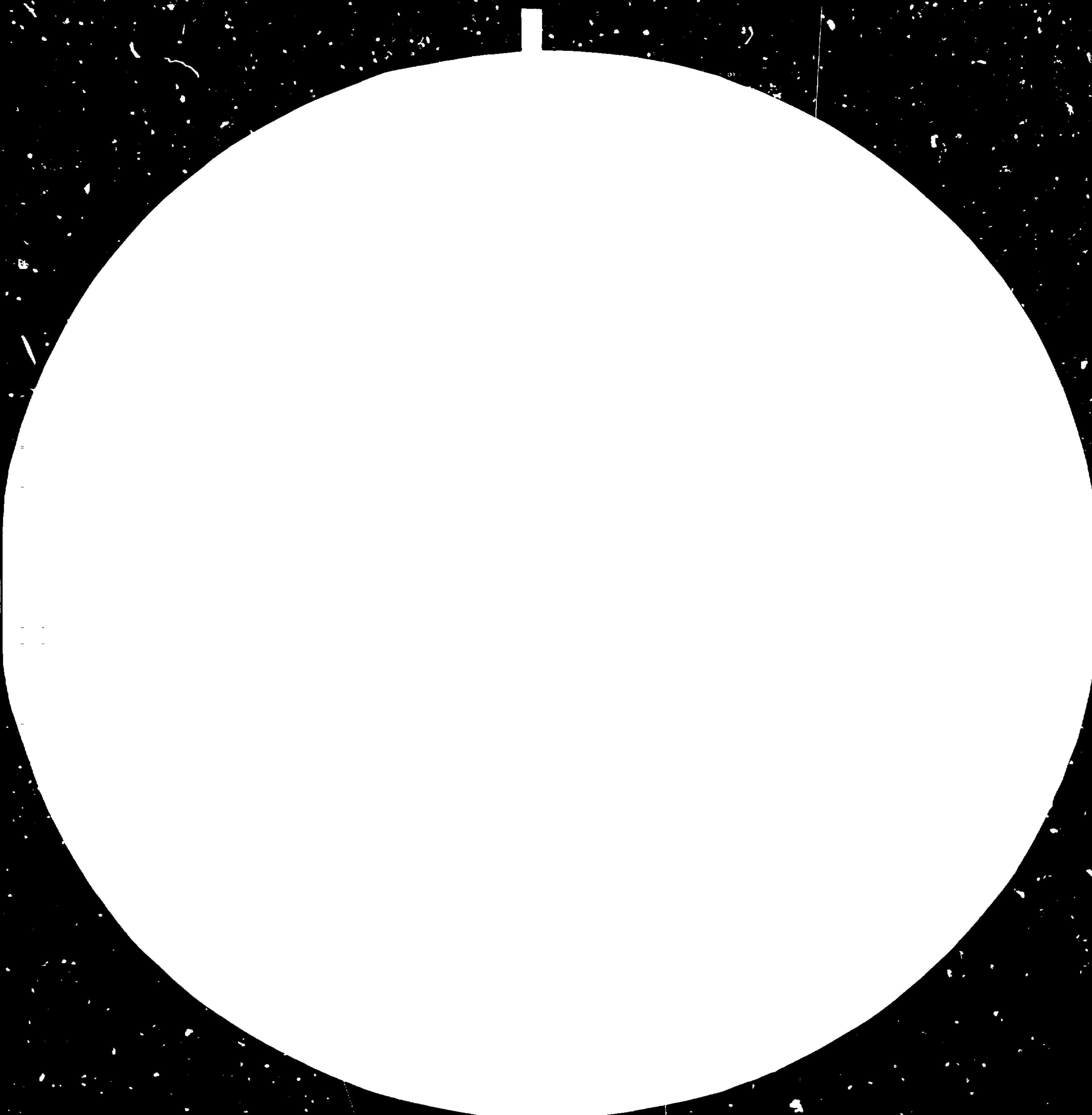

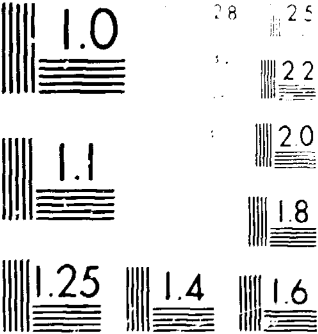
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EXCHANGE OF VIEWS WITH EXPERTS ON THE IMPLICATIONS OF TECHNOLOGICAL ADVANCES IN MICROELECTRONICS FOR DEVELOPING COUNTRIES

Vienna, 10-12 June 1981

BACKGROUND PAPER: BP. 2

LARGE-SCALE INTEGRATION: INTERCONTINENTAL ASPECTS*.

Prepared by

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Solid state

Large-scale integration: intercontinental aspects

Factors affecting the competitive positions of U.S., Japanese, and European firms include current business and economic climates

Ever since the invention of the integrated circuit (IC) and the silicon planar process, semiconductor producers in the United States have dominated the world markets for ICs, especially at the leading edge of each new generation of technology. This is certainly the case today for products of large-scale integration (LSI) complexity. But there are increasing signs that things might be changing.

Competitive memory products are now being produced in substantial quantities in Japan, and there is a growing interest by European companies in acquiring a stake in U.S. semiconductor companies. A key question is whether the global domination of the industry by U.S. companies will be seriously threatened, particularly as the very-large-scale integration (VLSI) era approaches.

The popular but simplistic view—widely held outside the United States—is that the U.S. domination of this industry has been based primarily on very substantial and continuous financial support from the U.S. Government, primarily through contracts. Whereas this funding has obviously been important, the real foundations of this success are far more complex and need to be understood in detail before the outcome of the impending intercontinental LSI/VLSI battle can be correctly forecast.

Indeed, any prognosis of future structural developments in this industry must begin with an understanding of the principal historical forces that have molded the industry into its present form. The reason, quite obviously, is that the important strategic influences now emerging will continue to be affected by those historical forces for the foreseeable future.

After looking at the historical development of the semiconductor industry in general, and ICs in particular, in the United States and Europe, it will be possible to identify the key factors that have led to the current U.S. domination of world IC markets. Then it will be possible to examine the new strategic forces now gathering momentum, and to project the future for IC producers as we enter the VLSI era.

Origins of the semiconductor industry

As is well known, the germanium transistor first went into high-volume production in the 1950s. Its most immediate application was in cheap, portable radios; the nation that seized this opportunity most effectively was Japan, which possessed at that time the considerable advantage of low labor costs. However, Europe (and Philips in particular) was not left far behind.

In the United States, the gleam in the electronics industry's collective eye was not caused by radios, largely because of the high U.S. labor costs. (The idea of moving labor-intensive assembly operations off-shore had not yet been tried.) Instead, the greatest need (what we might call the "user-pull," as distinct from the "maker-push," effect) for the transistor was mainly in the defense and aerospace sectors—1957 being the year of the Sputnik—and in the infant computer industry. The demands of these military and industrial sectors for devices of higher performance and reliability thus led in time to the emergence of the silicon transistor and later to integrated circuits—both developed by U.S. companies.

The final effects of these original, basic reactions to the advent of the transistor were as follows:

1. The Europeans and Japanese became strong in germanium technology and in the main types of equipment (i.e., consumer electronic products) that were based, at that time, on germanium transistors.

2. The U.S. became preeminent in silicon technology and in the main types of equipment based on it.

3. These distinctive postures, originally taken up 15 to 20 years ago, still pertain today: The Europeans and Japanese lead by a significant margin in most aspects of consumer electronics and the U.S. continues to dominate every other sector of the electronics industry.

Benefits of industrial synergism

What can be learned from this brief historical review is that a significant factor in shaping the development of the electronics industry in different geographic regions has been industrial synergism—the mutual interdependence of different industrial sectors and, in particular, of the equipment and component sectors of the industry.

With the advantage of this historical perspective, the principal factors that have affected—and in most cases will continue to affect—the development of the global IC industry can be identified. Almost from its beginning, the U.S. semiconductor industry as a whole has received substantial and broadly based support from various Government agencies. It has been estimated that between 1958 and 1974 this support totaled about $900 million for research and development alone, representing a subsidy of the cost of U.S. semiconductor innovation to the tune of about $55 million per year (in the terms of, say, 1965 average dollar values).

It is clear that financial support from public funds on such a large scale has grossly distorted normal competitive conditions and commercial criteria in this industry in the United States, and it is difficult to imagine, therefore, how any other nation could succeed without providing comparable support to its own indigenous industry.

The general, theoretical benefits of industrial synergism are familiar. However, it is useful to emphasize the par-

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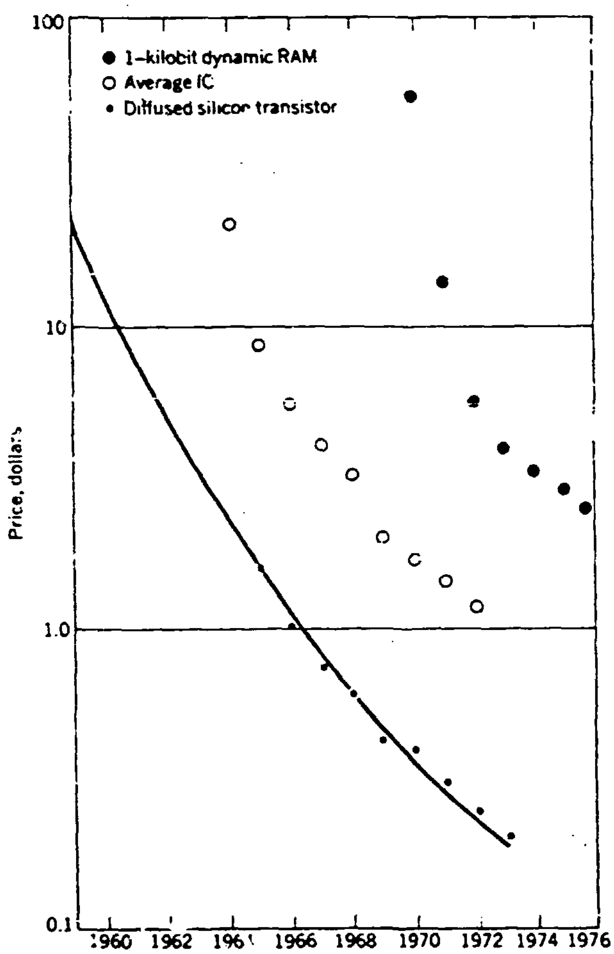
ticular importance of synergism in the development of the global IC industry.

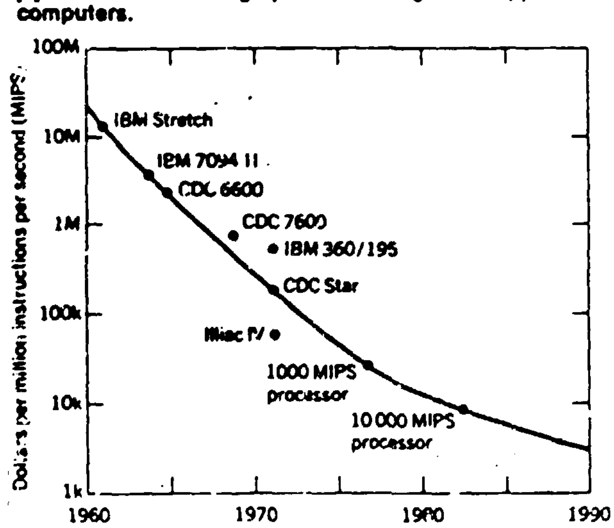
The well-known learning curve for silicon transistors and ICs reveals the systematic relationship between price and cumulative production experience. From that and other sources, it is possible to generate the price-trend curves (Fig. 1) for three silicon devices of progressively increasing complexity—the diffused silicon transistor, the "average" IC as defined by the learning curve, and the most recent 1-kilobit dynamic RAM.

Or consider the changes that have taken place in the performance/cost ratio of computers over the past 15 years or so. Figure 2 is a curve developed for the Rand



[1] Typical price trends for silicon devices.

[2] Cost trends for high-performance general-application computers.



Corporation. It shows the cost in dollars per million instructions per second (MIPS) for high-performance general-purpose computers for the years 1960–1990. Note that there is, so far, only one working version of the Illiac IV computer, and the 100-MIPS and 10 000-MIPS processors have yet to be developed.

Figure 3 shows the curve redrawn to give the greatest weight to actual, well-documented cost data. It is compared with the data from Fig. 1, normalized in time so that the prices are related to the number of years since production introduction.

The correlation between these two curves is striking, and proves what every IC engineer has always instinctively believed—that the computer industry's spectacular growth has been due mainly to its ability to produce equipment that could compute at ever-increasing speeds and reliability levels, and ever-decreasing cost and size. Essentially, all of these attributes have stemmed from advances in silicon technology.

But there is another side to the coin. Figure 4 shows the growth of the total U.S. consumption of monolithic silicon ICs over the period 1964–1976, with digital ICs indicated separately. Most of these digital ICs were used in computing equipment of all kinds (including military).

The conclusion is inescapable: Just as the U.S. computer industry's growth has been critically dependent on the availability of increasing numbers of ever-improved ICs, so has the spectacular growth of the U.S. IC industry depended to a very high degree on having a large, innovative, and "local" computer market eager to use its rapidly developing semiconductor capabilities.

This growth of the IC industry in the United States must be regarded as a particularly convincing example of the benefits of industrial synergism, and leaves no doubt that the simultaneous U.S. domination of the integrated circuit, computer, and professional electronics sectors are all part of the same basic phenomenon. This is the main, though not the only, reason that the United States dominates the worldwide IC business. The corollary is that the absence, until recently, of such synergetic user industries outside the United States has been the principal reason for the European and Japanese IC producers' early lack of success.

Technological innovation

Although innovation has been a major strategic factor in the growth of the international semiconductor industry, and will continue to be for the foreseeable future, the key elements of innovation are development and marketing, not basic research. In fact, there is no correlation whatever between the commercial success of an IC company and the quality of its basic research program. Historically, an ability to recruit key personnel has been much more important.

Disciplined in-house development of processes and products has been, and will remain, a key factor in any semiconductor company's success. However, for product development work to be relevant, the company must compete actively in the world's most innovative markets for those products—wherever those markets may be.

In Europe and Japan the process of innovation in the field of advanced semiconductor components has been hindered, until recently, by the relative absence of innovative user-pull markets and—especially in Europe—by too much emphasis on basic research and too little on development and marketing.

A recent development of enormous significance, and an excellent example of the innovative strengths of the U.S. IC industry, is the microprocessor. Its strategic importance stems mainly from its great commonality of application (Fig. 5), which allows LSI products to break out of the vicious circle of greater complexity—fewer applications—higher cost. The microprocessor offers as big a step forward for digital systems as did the original integrated circuit. Yet is is symptomatic that in this product area Europe has an almost insignificant capability so far, whereas Japan is already beginning to produce microprocessors on a modest scale.

Market factors

Access to large and innovative (user-pull) markets is a key factor influencing success in the IC business. Today, both Japan and Europe finally have developed large and innovative markets in the consumer electronics sector, but not in other industrial sectors. Hence, these non-U.S. producers have no choice but to aim for the maximum possible penetration of export markets. By and large, this means attacking the U.S. market; the beginnings of this attack are already giving cause for concern to some U.S. IC producers.

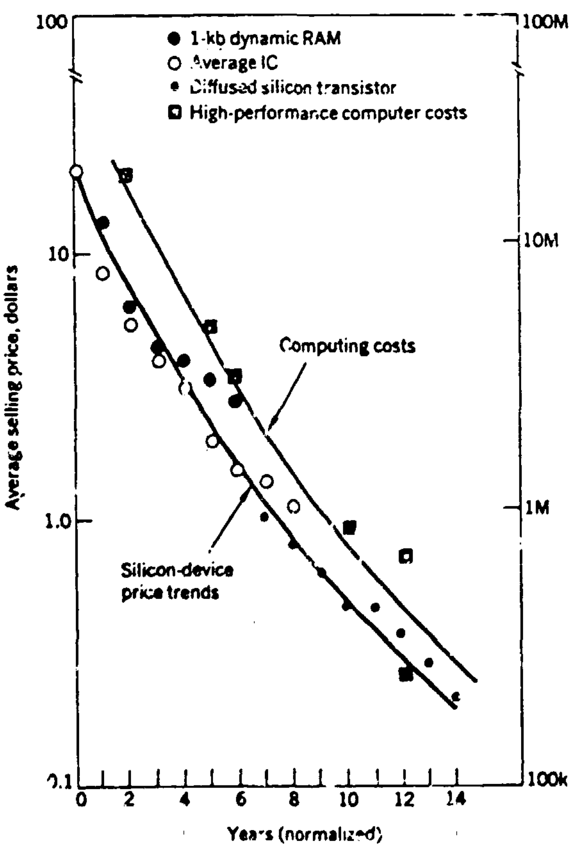
Table I shows Mackintosh estimates of the 1965, 1975, and 1985 markets for ICs in Europe, Japan, and the United States, in both absolute and per-capita terms. The preferential future growth rate of the Japanese and European markets is worth noting. Naturally, the high per-capita usage in Japan is related to high production of electronic goods containing ICs.

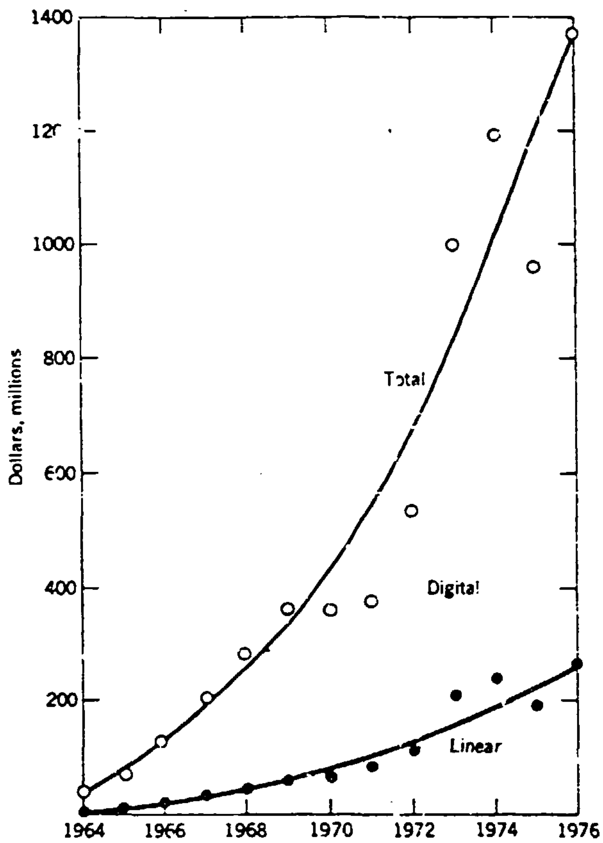
Industrial structure

Major differences exist between the structure of IC companies in the U.S. and those in other countries. In both Europe and Japan, the bulk of the current IC capability resides within vertically integrated and highly structured companies, whereas in the U.S., with the exception of organizations such as IBM and Western Electric, most of the IC capability resides in companies where the semiconductor activity is the major part of its total industrial commitment

Some blurring of these historically sharp differences has recently occurred through the various vertical integration moves that several U.S. component and equipment

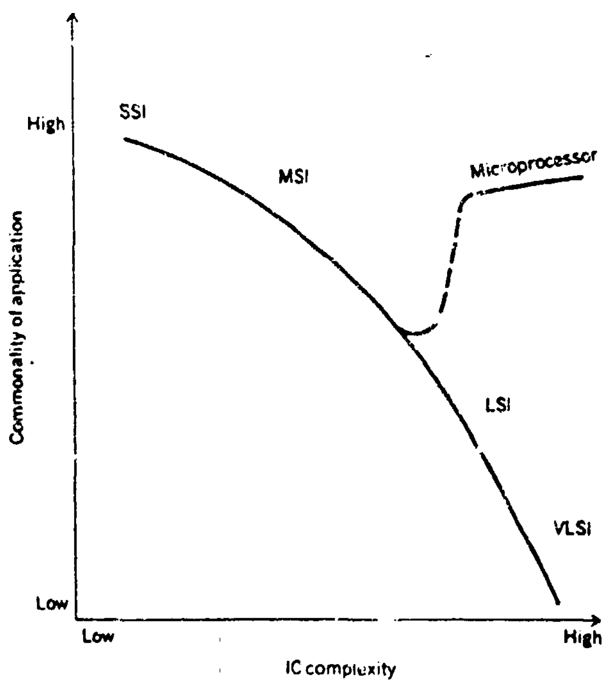
[3] Comparison of computing and silicon-device costs.





[4] U.S. consumption of monolithic integrated circuits.

[5] Complexity versus commonality.



I. Comparison of IC usage trends

	Estimated Total IC Consumption (millions of dollars)			Per Capita IC Consumption (dollars)		
	1965	1975	1985	1965	1975	1985
U.S.A.	60	1200	3500	0.3	5.7	15.9
European Economic Community	4	480	2200	—	1.9	8.5
Japan	7	480	1900	—	4.4	16.2

companies have made. In fact, the whole question of vertical integration is of great importance, and correspondingly great complexity.

In general, it is the writer's view that the vogue for vertical integration is an irrelevant diversion in the long-term development of the electronics industry. We live in an age of specialization, and it has for a long time been difficult to accept that IC companies can, for example, sell watches better than the established specialists. It has been equally difficult to accept that minicomputer companies can succeed in establishing and maintaining a cost-effective semiconductor capability over the long term.

Of course, there are the notable exceptions of IBM, Texas Instruments, and one or two others that seem to disprove the Mackintosh General Theory of Vertical Disintegration—i.e., the general hypothesis that vertical integration, by and large, is a snare and a delusion. However, apart from some special circumstances mainly centered on the microprocessor, this writer believes that of all the vertical integration activities, upward and downward, now going on in many parts of the world, only a few will turn out to be successful in the long term.

Management and people

Anyone who has worked extensively in the electronics industry, inside and outside the United States, will recognize that there often exists in other countries a real sense of inferiority about U.S. management skills. It is not just the general aura of infallibility surrounding, for example, a Harvard M.B.A., but the sheer bewilderment with which the typical non-U.S. electronics executive compares his apparent performance with that of his U.S. counterpart. This supposed infallibility is a misconception.

Table II, by and large, reflects the ability of U.S. management to bridge the gap between radically different technologies (vacuum tubes to germanium; germanium to silicon). Only one of the top ten U.S. vacuum-tube manufacturers in 1955 (RCA) has survived as a significant IC producer today.

The inescapable conclusion is that, popular opinion sometimes to the contrary, U.S. companies in general do not have a good track record in the management of electronics technology. A few, however, have obviously exhibited very impressive skills, and it is these successful managements, of course, on which the U.S. domination (and reputation) is based. What it all adds up to is that the United States' overwhelming success in the IC business has been, not surprisingly, something of a statistical phenomenon. With so many companies starting up, in such favorable conditions, some at least were likely to succeed in a big way. And some certainly did.

There are some other advantages that U.S. management has enjoyed. The distinguishing organizational feature of the successful U.S. semiconductor companies is that they are geared to react swiftly to new developments. They are also, in many cases, led by an impressive new breed of technical entrepreneurs who are skilled at this particular trade. In comparison, European and Japanese semiconductor companies have often been too ponderous in their decision-making and have sometimes been managed by individuals whose understanding of the semiconductor industry was somewhat less than perfect.

In the last analysis, the IC industry, like every other, depends on the right people being motivated in the right way to do the right job. In this sense, the United States has so far had most of the advantages since the evidence is very strong that entrepreneurial drive and freedom are essential conditions for success in the IC industry, and these are qualities that seem to thrive preferentially in the country's relatively laissez-faire economy.

The United States has also had a major advantage in the fortuitous combination of a high rate of personnel mobility with the existence of several large and highly capable research laboratories that have acted as national generators of technology and technologists. Thus, its diffusion of technology has occurred mainly through the diffusion of people, and the commercial exploitation of new techniques has rarely been inhibited for long because the possessor of know-how and the would-be exploiter could not make common cause.

In comparison, both Europe and Japan exhibit a considerably lower degree of personnel mobility, with the result that companies must rely on—and pay for—an in-house program of research and development that is proportionately much larger.

II. Leading U.S. manufacturers

	Tubes	1955 Transistors	1960 Semiconductors	1965 Semiconductors	1975 Integrated Circuits
1.	RCA	Hughes	Texas Instruments	Texas Instruments	Texas Instruments
2.	Sylvania	Transitron	Transitron	Motorola	Fairchild
3.	GE	Philco	Philco	Fairchild	National Semiconductor
4.	Raytheon	Sylvania	General Electric	General Instruments	Intel
5.	Westinghouse	Texas Instruments	RCA	General Electric	Motorola
5.	Amperex	General Electric	Motorola	RCA	Rockwell
7.	National Video	RCA	Clevite	Sprague	General Instruments
8.	Ranland	Westinghouse	Fairchild	Philco/Ford	RCA
9.	Eimac	Motorola	Hughes	Transitron	Signetics (Philips)
10.	Lansdale Tube	Clevite	Sylvania	Raytheon	American Microsystems

Another, indirect, consequence of high personnel mobility in the U.S.—particularly of technical and managerial personnel—has been the emergence of what can be called "skill clusters." So far as electronics is concerned, this can be applied to such centers as Boston's Route 128 and—of particular relevance today—to such areas of semiconductor expertise as "Silicon Valley" in California. (This phenomenon of skill clusters is by no means new. London's Savile Row tailors probably started the fashion about 200 years ago.)

It is abundantly clear that the existence of Silicon Valley confers important advantages on the IC companies that operate there, particularly in regard to the high (but informal) level of localized communication and debate, and to the availability of the strong common-services industry that has developed in that area.

Future prospects

It is not the aim here to provide a detailed forecast of IC technology per se, although in fact future technological developments will profoundly influence any strategic forecast of the IC industry. To that end, the evidence is now strong that a new high-resolution lithographic technology will emerge within the next few years, based probably on electron-beam techniques.

This VLSI technology will find application first in circuits requiring vast numbers of components (principally memory, microcomputers, and imaging), but will later be used also for numerically more mundane applications since by then the production economics will strongly favor VLSI against more classical technologies.

One major change that will occur within a few years is a substantial increase in the investment required to compete at the "leading edge." The industry will thus begin to move into an era in which the sheer size of the initial financial commitment will provide a stabilizing feedback effect, and there will be fewer opportunities for spin-offs to leapfrog into prominence by means of some astute technical, marketing, or economic stratagem. With this general scenario, then, the probable future changes in the key strategic factors can be considered (Fig. 5).

1. Critically important synergism with major industries.

2. Large and innovative domestic markets.

Much of the future growth in the world's markets for electronic functions is likely to be in domestic and personal-product sectors, not industrial. Despite the maker-push effect that the U.S. IC industry has so far exerted in such products as calculators, electronic watches, and video games, it is in just these areas of consumer, automotive, and personal electronics that Europe and Japan are strong. Thus, their budding IC industries have the prospect of the kind of critically important synergistic relationship with major user industries that the U.S. IC industry has enjoyed with its data-processing customers.

In addition, there is certain to be substantial growth, in both Europe and Japan, in "protected" applications like the telecommunications and "national" computer industries. Overall, then, there will be selective growth of the IC markets in Japan and Europe—much of it in user companies that, by corporate inclination or national preference, will tend to select "local" suppliers, all other things being equal. As a result, Japan and Europe will enjoy much greater parity with the U.S. in these areas.

3. Substantial government support over many years.

Until quite recently, the importance of government support had not been understood properly by the governments of many advanced nations, although things are now changing rapidly. In Europe, for example, the British, French, German, and Italian Governments are all beginning to talk about—and in some cases activate—plans to provide support that is typically in the $50–100 million range, and spread over four to five years. In Japan, there is, of course, the famous VLSI program about which it is very difficult to obtain hard facts. Our own best estimate at Mackintosh Consultants is that the purely Government funding for this project is about $65 million (in 1978 dollars) a year. There is little doubt that it will continue at about this level well into the 1980s.

In any event, several governments are beginning to support their indigenous IC industries with meaningful sums of money, so the United States' long-standing advantage in this respect will diminish, although substantial support of the U.S. industry can be expected to continue.

4. Suitable business climate for entrepreneurs.

5. Availability of substantial venture capital.

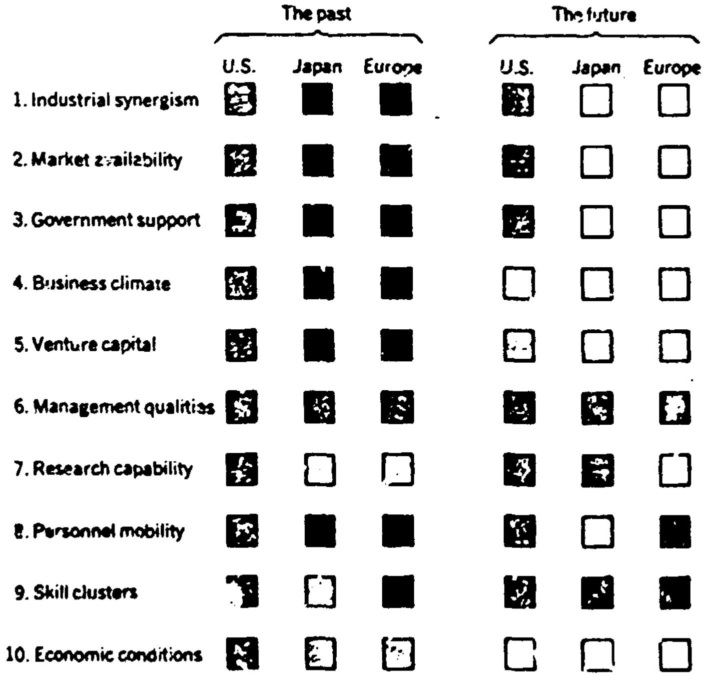
So far as the business climate is concerned, despite the probable stabilizing influence of the advent of VLSI technology, the entrepreneurial touch will remain an important ingredient of success in the IC industry. Long-term success will go only to those who can afford to exploit fully the most complex industrial technology yet devised, and who know how to do so. The multisector conglomerate will tend to lack the total commitment to success that is found in the specialist IC companies.

The U.S. will continue to have the edge over both Japan and Europe, where large corporations are unlikely to allow their semiconductor managers the same freedom of decision that their U.S. counterparts enjoy.

Nevertheless, the opportunities for new enterpreneurs in the United States will diminish as risks exceed acceptable limits. (Indeed, this has already been observable for some time, since there has been a sharp reduction in the number of new semiconductor companies.)

In both Japan and Europe, the financial community historically has been markedly unadventurous about pro-

[6] The shifting balance of advantage.



viding venture capital, and this situation is unlikely to change in the foreseeable future. On the other hand, the fact that the IC capability in these countries is mainly controlled by large companies could be an advantage because most will be capable of funding VLSI technology—especially with the aid of government support. The resource question, therefore, seems likely to become fairly evenly balanced in the future among the U.S., Europe, and Japan.

6. Enough good management in enough good companies.

In this writer's assessment, there is no significant difference between the inherent capabilities of executives in these different countries; managements in each of the countries seem to be about equally skillful (or incompetent) at creating commercial success from this esoteric semiconductor technology.

7. Existence of large, capable research laboratories.

8. Mobility of technical and managerial personnel

9. Skill clusters (e.g., Silicon Valley).

Taking the United States first, it is unlikely that its strength will diminish significantly in any of these areas. While there may well be some reduction in the amount of basic research carried out, this will be more than offset by increases in applied research in areas such as VLSI techniques, product testing, and software problems. Personnel mobility will certainly remain high, and it is very unlikely that any of the important U.S. skill clusters—whether they are called Silicon Valley, TI, IBM, Bell Labs, or whatever—will disappear.

In Japan, a systematic build-up of the national research capability has been under way for many years and will undoubtedly continue. For reasons that are well known, personnel mobility is low in Japan. This may change as joint ventures, company mergers, and Government policies slowly blur individual corporate identities, and increasingly permeate the Japanese way of life. As for skill clusters, the Japanese electronics industry is already mainly confined to the two metropolitan areas of Tokyo and Osaka. This clustering will be reinforced by an increasing number of cooperative industrial R&D activities, such as can already be seen in the VLSI program.

In Europe, however, things look distinctly worse. The United States and Japan are single nations, each with a single language, national sense of commitment, set of laws, customs, and cultural attitudes, whereas Europe represents a set of highly individualistic nations, each with its own language, national objectives, and way of doing things. Although this is so obvious that it may not even be mentioned, these factors are often overlooked.

Yet, because of the various differences that exist and the additional rivalries that occur as a result, there is not yet such a thing as a true Common Market, in spite of all of the efforts in that direction. Even such neighboring markets as France and West Germany can represent as great a problem in interaction as a far distant market like the United States.

With the exception of Philips, the semiconductor industry basically consists of a number of producers that are predominantly national in nature, each of which is organized principally to serve the needs of its own national markets. One of the liabilities that results from this situation is that Europe has nothing remotely to compare with California's Silicon Valley, nor is it likely that any meaningful geographical skill clusters will ever develop in the European IC industry.

For that same general reason, personnel mobility in Europe is also low, inhibited by both employment traditions and national boundaries, and is unlikely to increase significantly. However, the European research capability in solid-state electronics has always been high, though often commercially ineffective because it is unable to bridge the gap between science and sales. This research capability will improve due to increasing government support, and increasing cooperation both among European laboratories and with laboratories outside Europe.

10. Good fortune—including cheap energy and enormous international economic strength.

This really warrants a complete article in its own right if its relative importance is to be assessed accurately, but a few key points can be summarized briefly.

In the years since the end of World War II, the United States has dominated the economic health of the Organization for Economic Common Development (OECD) nations. This strength has been founded primarily on cheap energy, abundant natural resources, and a large enough population for the producers of manufactured goods to enjoy the benefits of considerable economies of scale.

Meanwhile, other nations—Germany and Japan, in particular—have been recovering from the ravages of war, and one of the pillars of U.S. economic strength has eroded as the dramatic increase of oil prices has coincided with the gradual depletion of U.S. oil resources. For the future, therefore, there is likely to be a much greater balance of economic strength among the United States, Europe, and Japan (Fig. 6).

What the future holds

There are many remaining strengths of the U.S. IC industry—such as its immensely strong technological base, its position on the learning curve, and management-in-depth. Also, European and Japanese management will still suffer from important liabilities such as the relative absence of entrepreneurial freedom. But even allowing for all this, there can be no doubt that the advantage is now beginning to swing away from the United States.

For this reason, in the VLSI era U.S. producers will face problems of daunting magnitude in maintaining global market share and innovatory leads against escalating transatlantic and transpacific competition. The most probable prognosis is that U.S. domination of this critically important industrial sector will eventually disappear, to be replaced by a condition of approximate parity between the United States and Japan, who may possibly be joined somewhat later by Europe. ◆

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I. M. Mackintosh (SM) formed Mackintosh Consultants, Ltd., in 1968, following stints as general manager at Elliott-Automation Microelectronics and as department manager in the Westinghouse Central Research Laboratories. During the 1950s, he was with Bell Laboratories in Murray Hill, N.J., and in 1957 published a paper describing his development of the first PNPN triode. Dr. Mackintosh served as industrial advisor to the U.K. delegation to OECD in its study of the technology gap.