# U.S. COMPETITIVENESS IN MANUFACTURING

Robert U. Ayres
*International Institute for Applied Systems Analysis*
*Laxenburg, Austria*

RR-89-6
July 1989

Reprinted from *Managerial and Decision Economics*,
Special Issue, Spring (1989).

**INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS**
**Laxenburg, Austria**

---

Reprinted with permission from *Managerial and Decision Economics*, Special Issue, Spring (1989).


---

Printed by Novographic, Vienna, Austria

# Preface

The author, Professor Robert Ayres, was not at IIASA when he wrote this paper, although he is co-principal investigator of the Computer Integrated Manufacturing (CIM) Project at IIASA. The subject of the paper is highly relevant and reflects some of his work at IIASA, so it seems worthwhile to make the paper available to a wider audience.

F. SCHMIDT-BLEEK
*Program Leader*
Technology, Economy, and Society

MANAGERIAL AND DECISION ECONOMICS, SPECIAL ISSUE, 3–12 (1989)

# US Competitiveness in Manufacturing

**ROBERT U. AYRES**

**Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA, USA**

**This paper reviews the 'competitiveness' debate from several points of view and then focuses attention on the longer-term prospects for US manufacturers. It concludes that, because US firms have had an earlier start in learning to use computers, leading-edge US firms are well situated to lead the way to fully computerized automation or 'computer-integrated manufacturing'. The current evidence is mixed but not inconsistent with the possibility that US-based manufacturers will be able to regain some lost ground in the next decade.**

## INTRODUCTION

The topic of this paper is at the center of a great controversy which, as often happens, confuses several different issues. For the sake of clarity, one should make an effort to distinguish them. One issue, itself compounded of several parts, concerns the long-term health of the US economy, the impact of 'Reaganomics' and the problem of debt, the trade imbalance and the federal deficit, and the instability and the apparent long-term weakening of the US dollar as an international currency. This may be termed the macroeconomic aspect of competitiveness. A separate but related set of issues that has been brought into focus recently by the Report of the President's Commission on Industrial Competitiveness [PCIC, 1985] and by a provocative book by Cohen and Zysman (1986) can be summarized by the question: does manufacturing really matter if we are moving into an era of services and information? There is a school of economists (among whom are some of the strongest advocates of free trade in the current debate) that believes (or seems to) that the 'hollowing' of US industry is a phenomenon of no intrinsic importance. They argue that this is merely a reflection of global restructuring and rationalization. By this logic, in fact, hollowing must be a good thing as long as it is a consequence of unfettered market forces.

A third, and conceptually distinct, question concerns the actual competitive situation of US manufacturing industry *vis-à-vis* Japan and Western Europe. Even with this narrower context it will be important to distinguish between various industrial sectors, since some are doing far better than others. A subtler but no less important distinction to be made is between the state of affairs as reflected in terms of current market shares and profitability and the longer-term prospects. This point is critical, because there is a spectrum of strategic responses between the 'quick fix' and the total rethink.

The paper will briefly sketch the context and then focus on the specific issue defined by the title.

0143–6570/89/SI0003–10$05.00


## MACROECONOMIC CONTEXT

Let us begin by recapitulating some of the 'good news'. In terms of GDP per capita in 'real' terms (adjusted for inflation and relative prices or 'purchasing power parity') the United States has actually gained on other major industrialized countries (with the exception of Japan) in the period 1970–85, according to OECD data (Ladd, 1987). For example, West Germany produced 83% of the US GDP per capita in 1970 and 89% in 1980, but this had fallen to 74% by 1985. The United Kingdom had 74% of US output per capita in 1970 but only 66% in 1985, and so on. Japan, which was at the 64% level in 1970, on the other hand, was only up to 71% by 1985. The period 1980-85, in particular, was good for the United States, or bad for Europe, or both. Of course, this was the period of soaring federal budget deficits, marked by an very large inflow of foreign capital. Perhaps it should not surprise anyone, on reflection, that Americans appeared to be producing much more per capita in 1985 relative to the other industrial countries (including Japan) than in 1980. We financed this extra growth, to some extent, with foreign savings. Nevertheless, these figures hardly seem consistent with the notion of a chronic and increasing lack of competitiveness. At the very least, one is forced to do some explaining away.

More macroeconomic evidence that requires some explaining away if the 'lack of competitiveness' thesis is to be sustained is the fact that employment in the manufacturing sector itself appears to be holding up remarkably well in numbers, though declining slowly in percentage terms. In fact, manufacturing employment in 1986 was almost exactly the same as in 1966, i.e. about 19.2 million workers (Birch, 1987). Yet employment in some important industries has undoubtedly declined considerably (as their unions can attest), and it is reported that the *Fortune* 500 companies have eliminated 2.8 million jobs between 1980 and 1986 alone. Clearly, something strange is going on. What appears to be happening is that, on average, large companies are getting smaller, at least in terms of their workforce. Even IBM has stopped adding new jobs. At the same time it seems that many small labor-intensive manufacturing firms are being started. It is these smaller companies that are creating the jobs that replace those eliminated by the large ones. In fact, according to the National Commission on Jobs and Small Business (NCJSB, 1987), firms with fewer than 500 employees generate 60% of all new jobs.

The trend toward smaller producers seems to hold true even in the troubled metalworking industry (Hicks, 1986). It is not hard to find examples of the decline of the giants and the rise of the pygmies. In the steel industry every large integrated producer has had to cut back considerably in both output and employment, and several have disappeared as a result of bankruptcy (for example, Youngstown) or merger (for example, Republic) or have restructured as much smaller companies (for example, National, Armco). Jones & Laughlin (J & L) is the latest casualty, but probably not the last. Yet scores of small, efficient, non-unionized 'minimills' have emerged in recent years, some of which have grown into major enterprises (for example, Florida Steel, Nucor). These companies have increased their market share continuously, and have been highly profitable. Some of them have also begun to introduce advanced new technologies. The minimill scenario is not unique. In other manufacturing sectors some small companies seem to be performing much better than most large ones. Since protectionism usually benefits the larger companies preferentially (after all, they pay for the lobbyists), a good case can be made that it would end up helping the inefficient and thus harming the efficient. This, however, is not the usual argument.

Not all the news is good, by any means, and even the good news may not be as good as it looks. The strong US performance in terms of aggregate job creation and GDP growth (adjusted for relative prices) is seemingly contradicted by the published data on productivity growth in manufacturing. This shows the United States lagging far behind Japan (and considerably behind France and West Germany) during the same fifteen-year period (1970–85), as indicated in Fig. 1.

Yet simple international comparisons of aggregate productivity growth may also be quite misleading in that output (the numerator of the productivity equation) is measured only in dollars, with inadequate allowance for changes in composition or quality. In particular, it is important to consider the increasing absolute share of computers and related products and the remarkable improvements in performance per dollar that have occurred since 1970. Whereas most products have changed relatively little in two decades in terms of performance, computers have changed considerably. Scattered data suggest that the cost of 'number-crunching' has fallen by more than a factor of 100 since 1970, and for some applications the difference is even greater. The US Department of Commerce finally generated a 'computer price index' in 1986, going back to 1972, which shows a more modest fifteenfold decline. However, there is, as yet, no estimate of the value (or cost) of the cumulative investment in software, without which the hardware would be useless. Yet it is commonly suggested that software costs now exceed those of hardware by as much as a factor of three.

Moreover, the United States is still far ahead of the rest of the industrial world in terms of the penetration of computers in some critical areas of use, notably office work and design applications. Bearing these points in mind, might not the standard 'productivity growth' figures be seriously misleading, as some have argued? The jury is still out on this question, largely because the evidence so far suggests that business consumers of computers have not (yet) demonstrated significant benefits, in the aggregate, from their very large cumulative investment. It seems, in short, that

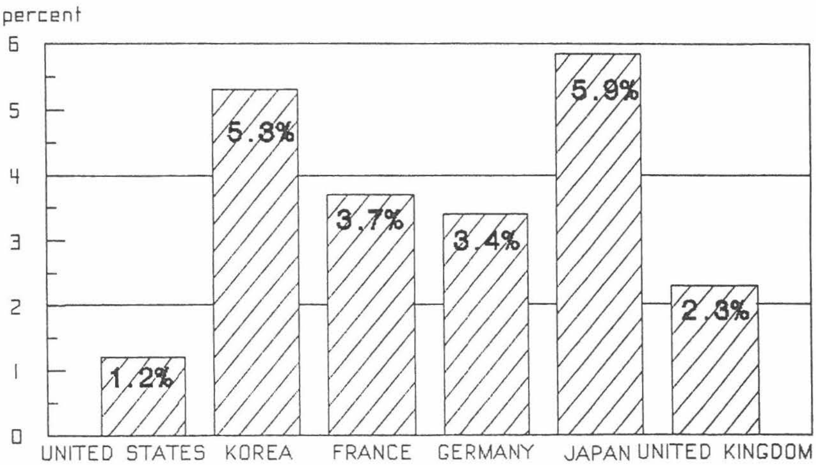


**Figure 1.** Productivity (real GDP per employed person): average annual percentage change, 196063. (Source: US Department of Labor, Bureau of Labor Statistics, December 1984 (unpublished).)

'white collar' productivity has not been increasing (Strassman, 1985; Baily, 1986; Bowen, 1986). Indeed, a detailed study of the financial industry (banks), which was one of the first to adopt computers on a massive scale, and for which very good data are available, reveals that capital intensity has increased significantly since 1960 while real return on equity has declined sharply (Franke, 1986). Thus the productivity of capital has plummeted. Based on an index of 100 in 1948, capital productivity measured 113.83 in 1960, 66.65 in 1970 and only 28.12 in 1983. During the same period, labor productivity increased slowly from 120 (1960) to a peak of 140 (1975) but has declined since then (Ibid).

There are several possible explanations for these phenomena, but the 'bottom line' is that the available productivity statistics could just as well be interpreted as implying that productivity growth has slowed down in the financial sector precisely because it invested a lot of capital in ultimately unproductive ways. Since computers accounted for roughly one third of all investment in producers' durable equipment in 1982 and every dollar of expenditure on computer hardware entailed up to three dollars of expenditure on software (mostly uncapitalized) the same general conclusion might possibly hold for the whole US manufacturing sector. The correct interpretation of these numbers must await future clarification by events.

## MICROECONOMIC CONTEXT

The most direct measure of competitiveness is ability to sell in world markets. Here, too, the recent trend has been very disquieting (see Figs 2 and 3). The United States has had a trade deficit in raw materials and 'low tech' manufactured products for two decades, but until recently this has been compensated, in part, by a substantial and reliable surplus in the so-called 'high tech' sector, including computers, semiconductors, telecommunications gear, aerospace and pharmaceuticals. In 1980 the positive trade balance in these sectors amounted to $26.6 billion, but in 1982 this figure began to fall sharply. It became negative, for the first time, in 1986, when the United States imported $2.6 billion more in the 'high tech' sectors than it exported. Undoubtedly the sharp rise in the US dollar from 1982 through spring 1985 contributed, but the dollar has fallen nearly 50% since then against all major foreign currencies, with only a modest and recent improvement in the trade picture. Part of the reason has to be that many US plants have closed

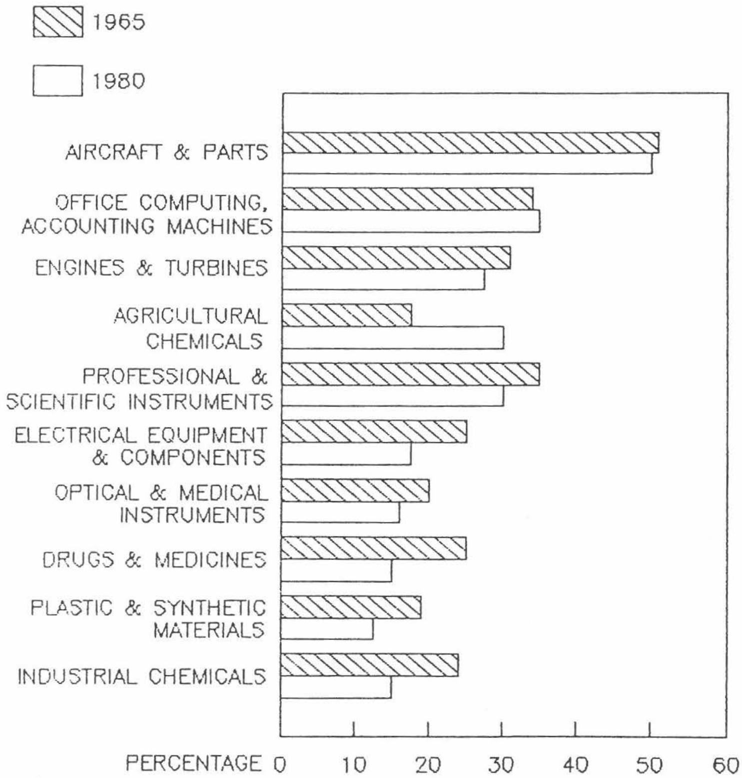


**Figure 2.** US shares of world high-technology exports, 1965 and 1980. (Source: US Department of Commerce.)

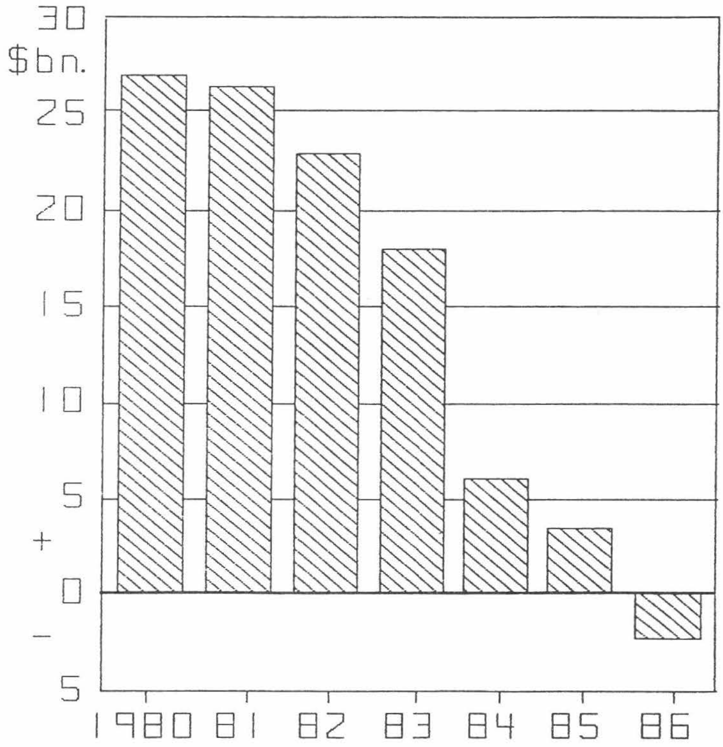


**Figure 3.** US high-technology trade balance. (Source: US Department of Commerce.)

permanently and many manufacturers are now so dependent on foreign suppliers that a declining dollar merely increases their costs.

In some industries the US manufacturers have disappeared, or nearly so: examples include mass transit equipment, motorcycles (Harley-Davidson has returned from near-bankruptcy, with help from the government, but it still has a very small market share), radios, tape-recorders, hi-fi audio equipment, televisions (except for Zenith), watches, cameras (except for Polaroid) and small digital pocket calculators. Another major loss is the low-priced end of the xerographic copier business, which was a worldwide monopoly of the Xerox Corporation as recently as 1970 before its patent protection expired.

Even in the semiconductor industry, which was created in the United States less than a generation ago, significant segments seem to have moved to Japan permanently. For example, the specialized ceramics used for chip substrates are almost a Japanese monopoly. The United States now has only 5% of the merchant DRAM (Dynamic Random Access Memory) chip market, which was initially created by the innovation of Intel Corp in 1969 (Fig. 4). Intel itself has long since abandoned that business because of losses. In fact the US Defense Department has become so concerned about the erosion of US manufacturing capabilities in this field that a $250 million per year industry–government venture, called Sematech, is being pushed through Congress by the Pentagon. It is worth noting that Charles Sporck, President of National Semiconductor—and one of the strongest industrial proponents of the proposed government intervention—has been quoted as saying that, even if Sematech is launched, it would take five years to 'catch up' with the Japanese (Sporck, 1987).

There are major long-term costs associated with dropping out of any important technology market. For example, when US manufacturers were beaten by the Japanese in the fast-growing digital watch and pocket calculator industries in the early 1970s they also fell seriously behind in the race to develop the specialized chip-making technology (CMOS) that was utilized for very low-power consumption devices. This became a Japanese speciality. Later it was the preferred technology for DRAMs, which partly explains why the Japanese also took that market away from US firms. CMOS devices are also becoming very important in the telecommunications industry, which requires many devices such as amplifiers and repeaters that are powered by the very low voltages in telephone circuits. US semiconductor firms are now trying to get back into this field, but the Japanese have the lead today. In fact, the Materials Advisory Board of the

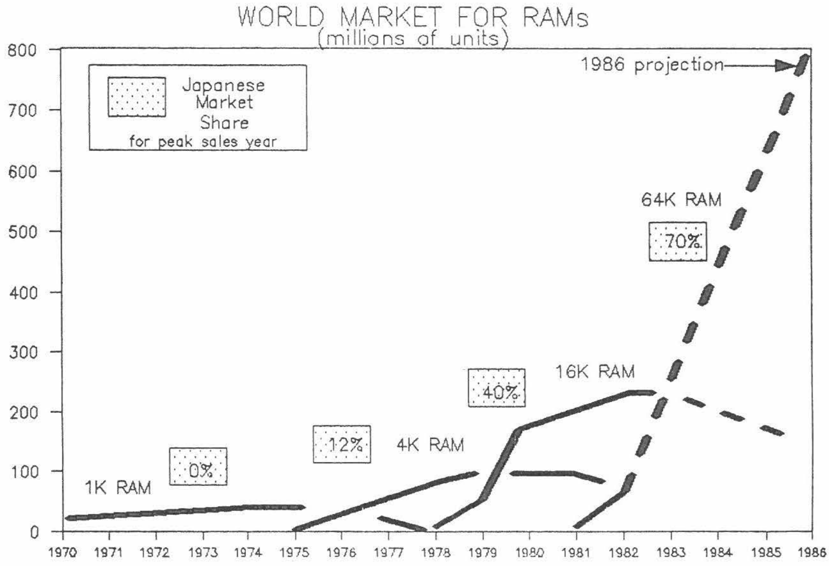


**Figure 4.** World market for RAMs (millions of units). (Source: *Dataquest.*)

National Research Council has recently reported that they are leading the United States in seven out of ten important emerging materials-related technologies, including optical lithography and optoelectronic integrated circuits. The latter may be the most important single technology of the 1990s (Robinson, 1986a).

Small, high-performance, reliable mechanical devices have long been a Japanese specialty. Beginning with cameras, watches and tape recorders, Japan now also makes the majority of the printers, disk drives, keyboards and monitors used in personal computers. In fact, nearly 75% of the manufacturing value-added for the original IBM PC was from Japan, Singapore or South Korea, and only the final assembly was carried out in the United States. Growing Japanese expertise in precision manufacturing also found ready application in the automotive and machine-tool industries, including their offshoot, the robotics industry. It is no accident that one of the leading manufacturers of precision assembly robots is Seiko, the world's largest watchmaker, which developed its first industrial robots to assemble watches. The high standards of quality associated with Japanese products in general owe a great deal to the experience gained in the consumer product lines that Japan took away from the United States and Europe in the 1960s.

While US manufacturers are learning some lessons and improving their own performance, many of the losses are likely to be permanent. For example, Nissan's US subsidiary (Smyrna, Ohio) has a 'local content' of about 60%, but only 37% of the components it buys from outside suppliers are US-made. In the case of Honda, the most successful of the Japanese 'immigrants', local content is only 45%. A Honda spokesman has commented in regard to this (*Financial Times*, 1987):

American vendors are now doing well on quality and price. But there is a wide variety of parts we need for which the technology and design capability simply does not exist in the US.

The recent bloodbath among US machine-tool and robot manufacturers is certainly attributable, in part, to the fact that Japanese manufacturers of the basic components, such as motors and motor controls, not to mention gearwheels, nuts and bolts, are now more competent than their US counterparts. Unimation, the robot pioneer which had about 40% of the US market when it was aquired by Westinghouse in 1983, saw its sales drop by nearly a factor of two (from $70 million to $38 million) during a three-year period when total worldwide sales of robots increased considerably. The Cincinnati Milacron T3 robot did not fare much better. The problem was that both robots were (and are) hydraulic machines, which were strong and reliable but comparatively inaccurate. When industry demanded greater accuracy—which could only be provided by electrically driven machines—Unimation/Westinghouse and Cincinnati Milacron were too slow to respond, and the advantage passed quickly to Japan.

The story in machine tools has been similar. In the mid-1970s the United States was a net exporter, due in part to a technological lead in numerical control technology. The great investment in new plants and equipment by the US auto industry following the 1973–4 'oil shock' resulted in a period of great prosperity for the domestic machine-tool industry in the late 1970s, but it also led to lengthening delivery times and opened the door for foreign competition. The Japanese sharply increased their capacity to meet this demand, and then reacted to the recession after 1981 by cutting prices and standardizing products. The US share in world production of machine tools fell from 19.4% in 1981 to only 10.8% in 1983, with a slight rebound to 12.7% in 1984, whereas the Japanese share rose from 11% to 22.5% in 8 years (Fig. 5). From 1981 to 1986 300 out of 800 US machine-tool manufacturers have disappeared, and employment fell from 110 000 to 70 000 (Wall Street Journal, 1987). The survivors are mostly in severe financial difficulties, and unable to finance either new product development on a significant scale or modernization of their own obsolete production facilities.

The demand for machine tools began to pick up again after 1983, but foreign firms now command nearly 50% of the US domestic market. Worse, major categories of machine tools are no longer available from US producers. One of the most telling illustrations is the fact that when GM recently retooled its body-parts plant at Mansfield, Ohio, it replaced old, manually operated stand-alone presses by a set of programmable ones linked by a transfer line. US producers lacked the experience and the ability to manufacture these machines in the required size and Japanese and West German firms got the business. The Japanese manufacturer, in particular, was able to develop the technology because it had assurances of a market to the Japanese auto industry, something GM would not give any US manufacturer. The next time a US auto company wants to buy such equipment it will probably have no option except to buy Japanese.

The problem, in short, is that competition can have favorable effects on efficiency and entrepreneurialism, but not all effects are favorable. When competition is extreme, the losers go out of business and the winners gain a lead that may be permanent and insurmountable. The United States has already lost a lot of its industrial capability, and much of what remains is vulnerable to further erosion.

## HOW ARE WE DOING IN THE RACE TO COMPUTER-INTEGRATED MANUFACTURING?

The main arguments to be made in the remainder of this paper are as follows. On the one hand, although the United States was the source of almost all the key technological innovations (to date) needed for CIM it has been slow to apply some of this new technology on the factory floor. Not only Japan but also Sweden and West Germany (as well as East Germany and Czechoslovakia) have forged ahead in certain areas such as applications of numerically controlled machine tools, robots and manufacturing cells or 'flexible manufacturing systems' (FMS). Recent trends in the latter area are summarized in Fig. 6.

On the other hand, there is no doubt that the United States is still ahead of the rest of the world, including Japan, in applications of microcomputers (PCs), computer-aided-design (CAD) and in manufacturing areas that depend very heavily on design, such as microprocessors and computers themselves. For example, continuing US strength in commercial airliners and jet engines can be attributed to this advantage, in all probability.

The evidence of US competitive strength in these design-intensive areas is not hard to find. Despite undoubted Japanese strength in microelectronics and high-precision 'mechatronics', Japan has yet to make significant inroads in the US market for personal computers—by far the world's largest ($22.5 billion in 1986). IBM is being challenged mainly by other US manufacturers such as Apple, Tandy, Compaq and Zenith. (However, Japanese firms are entering the market with lap-top portables.) In the minicomputer market DEC has recently strengthened its lead over (mainly American) rivals like IBM, Data General, Hewlett-Packard, Prime and Honeywell. The world

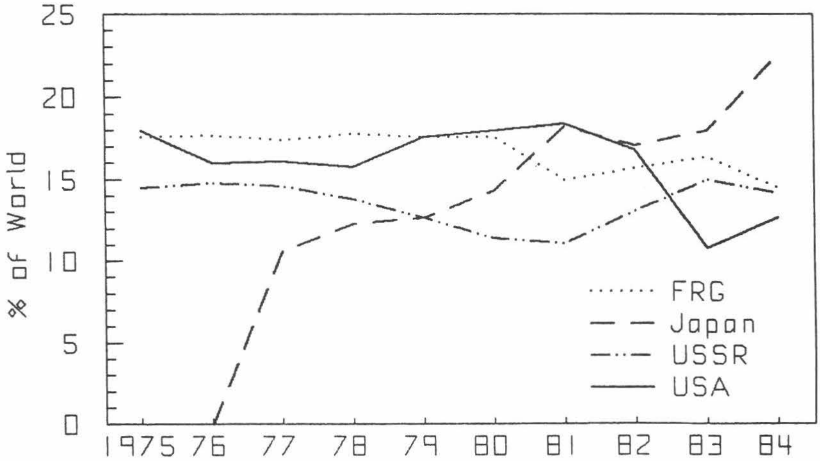


**Figure 5.** Machine-tool production of selected countries: percentage share of world totals. (Source: ECE, 1986.)

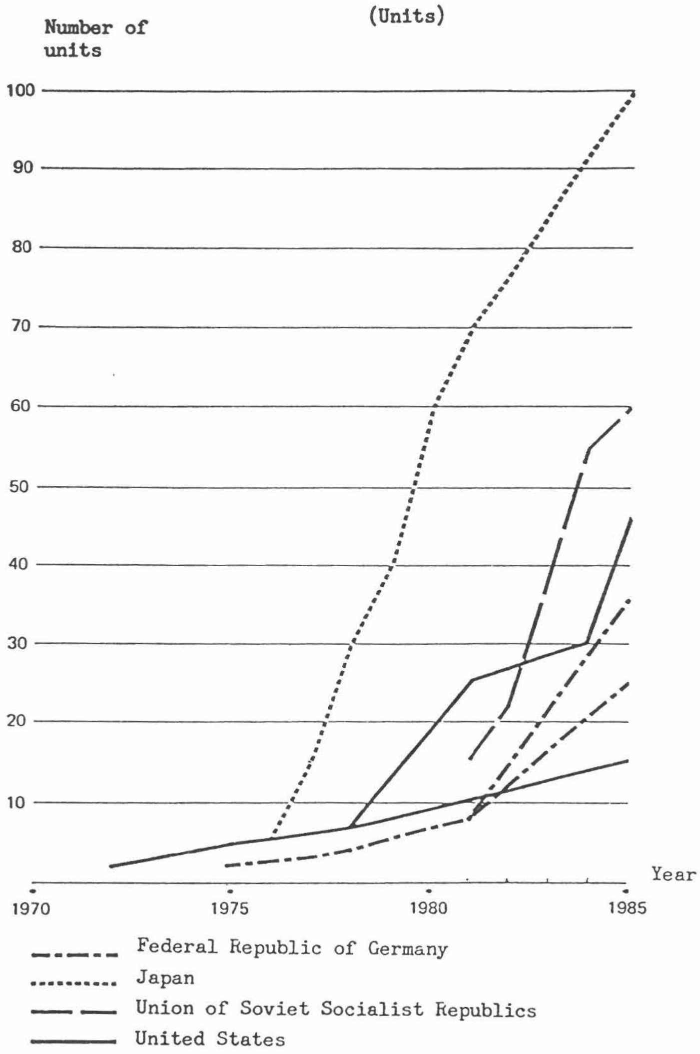


**Figure 6.** Growth of FMS in West Germany, Japan, the USSR and the United States (units). The two curves for the United States apply to a wider and a stricter definition, respectively, of FMS. For West Germany an interval estimate is given for the number of FMS installed at the end of 1984. (Source: ECE, 1986.)

market for packaged CAD systems in almost a US monopoly, with pioneer Computervision being challenged by Intergraph and half a dozen other US companies (including GE, IBM and Apple). Engineering workstations is another area of US dominance, with Sun Microsystems, Apollo, Convergent Technologies, IBM and others fighting for temporary leadership. In this important corner of the industrial world there is no doubt of US competitiveness. On the other hand, Gilder (1987) is an order of magnitude too optimistic in saying 'While American economists ululated about declining competitiveness, we won the competition'.

In all fairness, the competition is not over—far from it. Neither Japan nor, for that matter, Western Europe has withdrawn or conceded defeat. Japan's 'fifth generation' computer project has brought that country far closer to the research frontier than was the case a decade ago and, if past experience is to be relied upon as a guide, Japanese strength in manufacturing is likely to tip the balance away from the United States in any area of technology that emerges from the fast-changing 'childhood' phase of the lifecycle into the 'adolescent' one, with its greater emphasis on standardization and cost reduction to propel market growth. Sometimes this transition occurs almost overnight, as in the case of the DRAM. There is reason to believe that such a transition may be coming shortly for microprocessor technology, in that the recently introduced 32-bit microprocessors (Motorola and Intel) are not likely to be replaced by 64-bit designs for many years, if ever. This could be the opening the Japanese have been waiting for to make their move into the mini- and microcomputer business.

The unresolved question that remains is: can US-based manufacturers hope to compete in the future? Can they hope to make up lost ground? There are no firm answers to these questions. The situation is, to say the least, 'fluid'. However, there are indications—so far, rather scattered—that the worst of the rot may be over. As for the prospects for regaining lost ground, it is possible, but very far from certain.

The adverse factors have been widely discussed. Among them are the short-term 'bottom line' orientation of many US executives, especially those trained to think of manufacturing operations only as financial assets (for example, Hayes and Abernathy, 1980). Another persistent problem cited by some economists (albeitd is pointed to others) is the relatively high real cost of capital in the United States compared with Japan. (Hatsopoulos, 1986). Still another serious institutional problem is the way in which the traditional rules of accounting (inadvertently) induce managers to focus excessively on labor cost reduction (bearing in mind that direct labor typically accounts for only about 15% of total manufacturing costs, down from 25% in 1970) while neglecting other, more important opportunities for improving performance such as inventory reduction and quality improvement (Kaplan, 1986; Howell *et al.*, 1987).

A further fundamental problem is the scarcity of manufacturing engineering talent in the United States compared with Japan and West Germany. There is growing evidence that this scarcity is largely attributable to the squeeze between a limited supply, on the one hand, and increased demand for engineers by defense industries, on the other. Supply problems, in turn, are partly due to the long neglect of science and mathematics education in secondary schools, aggravated by the withdrawal of federal resources from higher education in general. Another factor in the equation is the superior financial attractiveness of law and business careers to the best and smartest students. Taking all these points into consideration, the manufacturing engineering shortage in the United States is likely to continue for many years.

In addition to the managerial and educational factors tending to reduce US competitiveness, government policy plays a very significant negative role. It is indisputable that many policies, from antitrust, to immigration, to international security-motivated export controls, have hurt US firms' ability to compete internationally. The so-called 'CoCom system', which is supposed to co-ordinate such restrictions among all industrialized countries, has been, in practice, a bad joke. This was recently revealed by the willingness of Toshiba to sell its most advanced nine-axis machining centers directly to the Soviet Union for the purpose of manufacturing submarine propellers, while the Pentagon has successfully prevented US firms from selling commercial products such as 32-bit microcomputers and chip-making equipment, even to Western countries in some cases. The recent bankruptcy of GCA Corp., formerly the leading manufacturer of some categories of advanced chip-making machines, has handed over this market to Nikon and Canon. This unfortunate event can probably be laid at the door of the Pentagon, which interfered with GCA's attempts to sell in Asia.

Worse, from the point of view of competitiveness, the Pentagon often does not buy advanced commercial products already available, preferring obsolescent hardware developed to its own specifications from its established network of suppliers. Thus the role of the military in providing sustaining domestic markets for innovative technologies has declined sharply since the 1950s and 1960s. Meanwhile, lack of effective competition, or excessive tinkering with designs after production has started, have resulted in very large cost differentials between military and civilian production, even for very similar items. The net effect is to choke off the transfer of military technology to civilian purposes and the economic benefits that formerly accrued from this process.

Having said all this, there is actually some good news to report. There are some farsighted leaders in US industry who have decided to invest in long-term survival as manufacturers by trying to skip a technological generation, despite the negative short-term impact on profitability and declining popularity on Wall Street. Whereas the United States has unquestionably lagged in terms of retrofitting robots and manufacturing cells or FMS in existing plants (Jaikumar, 1986), some of the 'flagships' of US manufacturing industry such as IBM, Kodak, Boeing, General Electric, Westinghouse, General Telephone and General Motors have invested tens of billions of dollars in completely redesigned computer-integrated manufacturing (CIM) systems going far beyond the introduction of robots or FMS *per se*.

The early returns have not all been favorable. For example, both IBM and GM have apparently slipped in terms of short-term profitability in comparison with their closest rivals. There have been setbacks, some of which are reported in the *Wall Street Journal*. For instance, it is said the GM's new Hamtramck assembly plant, which cost $500 million, is no better in quality and productivity than the GM–Toyota joint venture in the old Fremont (Cal) plant, which is much less technologically advanced, but utilizes Toyota's system of management (*The Economist*, 1987). GM's $400 million new Buick City facility at Flint also incorporates major technological advances, including flexible tooling, but it took twice as long to get the new system debugged as had been planned, and some critics are saying that its expected benefits are illusory. The ambitious Saturn project is now the subject of considerable second-guessing, and GM has resorted to major layoffs of middle managers to improve its short-term financial performance. In a similar vein it is said that GE paid too much for its $600 million CIM dishwasher plant in St Louis, as did IBM for its new $350 million CIM typewriter plant in Lexington, Ky.

On the other hand, some of the new plants appear to be resounding successes, by any standards. For instance, Westinghouse's new College Station (Tex) circuit-board assembly plant cut space requirements by 40%, labor content by 45%, inventories by 55%, material losses by 70% and manufacturing cycle time by 75%. Moreover, the parent plant (Baltimore) was getting a 15–20% composite yield in 1980—typical of US plants. At College Station the yield of perfect circuit boards, on the first pass, is now up to 95% and rising (Murrin, 1987).

It is possible that, from the longer-term perspective (which US executives have been accused of neglecting), the 'disappointments' that have been experienced are the inevitable and necessary cost of learning how to integrate a factory and link it, by computer, to others. Subsequent attempts will be less expensive and will work better. Fewer mistakes will be made.

General Motors, for one, is far too deeply committed to back out. Its factories contain some 200 000 programmable machine tools and robots. GM intends to link its many 'islands of automation' together (i.e. make them communicate with each other) and put them all under the control of centralized computers. To do so it has pioneered the creation of a 'manufacturing automation protocol' (MAP), to which over 1000 manufacturers of computers, controls and programmable equipment have already subscribed. It purchased Electronic Data Systems (EDS) for $2.6 billion to facilitate the process. GM began the actual 'wiring up' at a truck assembly plant in Pontiac, Mich, in the spring of 1986. The company has targeted 1990 as the deadline for having all its new flexibly automated plants interconnected and linked by MAP to the corporate headquarters.

The critics, both inside and outside the company, who point out that Toyota currently achieves results as good, or better, without fancy automation are probably missing the point. Toyota may be able to achieve still better results in the future than it does now, by continuing along its present lines of incremental improvements with minimum automation, but it will eventually have to do what GM is doing now, while competing with a tougher adversary. Meanwhile, GM can apply the lessons it is now learning from Toyota at Fremont to make still further gains of its own in the future if, needless to say, all goes according to plan.

As of the middle of 1988 it has been estimated that the United States has already built as many as 130 CIM factories. By comparison, there are very few—if any—in Europe or Japan. Since this very large investment (about $50 billion from 1981 through 1986) has yet to pay off in terms of measurable increases in productivity or improvements in the balance of trade it is being derided as a failure. To be sure, even Ford and Chrysler cannot afford to spend on GM's scale, and most companies must be far more modest in their ambitions. On the other hand, most companies do not have GM's considerable bureaucracy and ingrained NIH ('not invented here') tradition to be overcome. For a smaller company, needless to say, the necessary scale of investment is also smaller. What such companies cannot afford is to pay a disproportionate share of the learning costs only to have the benefits become quickly available to competitors. However, it is increasingly clear that this is not a real problem, in the case of CIM, in that the knowledge of 'how' to integrate is not the province of computer companies (except in their own plants) nor that of the consulting engineering companies. Each company really has to do the job for itself, first by understanding its own manufacturing process thoroughly, then by simplifying it as much as possible and finally by automating and computerizing. A thorough job of training (or retraining) the labor force is also a prerequisite to success.

The major lesson of the well-publicized 'failures' is probably that the simplification step had been given too little attention, relative to the computerization. The Japanese are particularly effective in this area, which accounts for much of their current competitive success. One succinct summary of the strategy now being adopted by many US firms is 'learn what the Japanese do, then automate it'. The first half of this strategy is now well under way and the second half is beginning. The comparative advantage may shift, since US firms have invested much more in computers—especially software—over the past 30 years than either Japanese or Europeans. Whereas Japanese manufacturers are much more efficient on the plant floor than their US counterparts, the opposite may be true in the office. Certainly, the United States is far ahead in terms of office applications of PCs (about 10:1). Although the payoff from hundreds of billions of dollars of computer investment is hard to measure (at least in terms of 'white collar productivity'), the fault may well be in the measurement methodology, or it may be that gains have been obscured by other factors such as additional paperwork imposed by government regulation or created by bureaucratic middle managers.

Most likely, a major obscuring factor is the length of time it has taken people (and organizations) to learn to use these tools properly. If this is true, then European and Japanese firms still have much of this learning ahead of them. Thus while far from certain it is not implausible that the benefits of CIM will be achieved first by the United States. In this case the current situation of poor US performance in international competition may only be temporary. The next few years should be interesting.

## REFERENCES

M. N. Baily (1986). What has happened to productivity growth? *Science* **234**, October, 443–51.

D. Birch (1987). Is US manufacturing dead? Inc. June.

W. Bowen (1986). The puny payoff from office computers. *Fortune* May.

S. Cohen and J. Zysman (1986). *Manufacturing Matters*, New York: Basic Books.

ECE (1986). *Recent Trends In Flexible Manufacturing*, Research Report, Economic Commission for Europe, Geneva.

*The Economist* (1987). Anon. Factory of the future. 30 May.

R. H. Franke (1986). *Technological Revolution and Productivity Decline: Computer Introduction In The Financial Industry* (Unpublished).

G. de Jouguieres and A. Kaletsky. *Financial Times* (1987). Can America make it? 11, 13, 18, 20 May.

G. Gilder (1987). Don't let the grinch steal Christmas. *National Review* 24 April.

G. N. Hatsopoulos (1986). Productivity lag is real trade barrier. *Wall Street Journal* 14 May.

J. Hayes and W. J. Abernathy (1980). Managing ourselves into an industrial decline. *Harvard Business Review*. August–September.

D. Hicks (1980). *Automation Technology and Industrial Renewal*, Research Report, American Enterprise Institute, Washington DC.

R. A. Howell, D. Brown, S. R. Soucy and A. Seed III (1987). *Management Accounting in the New Manufacturing Environment: Current Cost Management Practice In Automated (Advanced) Manufacturing Environments*, Research Report, National Association of Accountants and Computer Aided Manufacturing-International.

R. Jaikumar (1986). Postindustrial manufacturing. *Harvard Business Review* November/December.

R. S. Kaplan (1986). Must CIM be justified by faith alone? *Harvard Business Review* March/April.

E. C. Ladd (1987). US competitiveness—by the numbers. *Christian Science Monitor* 18 May.

T. J. Murrin (1987). *The Quest For Quality: Integrating Technology and People*, NEPCON/West 87, Westinghouse Electric Corp., 25 February.

NCJSB (1987). *Report of the National Commission on Jobs and Small Business*, Research Report (4), National Commission on Jobs and Small Business, Washington DC, February.

PCIC (1985). *Global Competition: The New Reality*, Research Report, President's Commission on Industrial Competitiveness, Washington DC, January.

A. L. Robinson (1986a). A chemical route to advanced ceramics. *Science* **233** (4579), 4 July, 25–7.

A. L. Robinson (1986b). US electronics needs new strategy. *Science* **232**, 20 June.

C. Sporck (1987). *Nature* **327**, 178 May.

P. A. Strassman (1985). *Information Payoff: The Transformation of Work in the Electronic Age*, New York: Free Press.

*Wall Street Journal* (1987). Anon. Ground down: US machine tool makers lose out to imports because of price and quality. 17 August.