A list of Working Papers on the last pages

No. 96

THE MACHINE TOOL INDUSTRY - PROBLEMS AND PROSPECTS IN AN INTERNATIONAL PERSPECTIVE

by

Bo Carlsson

This is a preliminary paper. It is intended for private circulation, and should not be quoted or referred to in publications without permission of the author. Comments are welcome.

December, 1983

ABSTRACT

The Machine Tool Industry -- Problems and Prospects in an International Perspective

by

Bo Carlsson

The Industrial Institute for Economic and Social Research (IUI), Stockholm, Sweden

The machine tool industry is tiny but crucial: it supplies the machines to cut, form, and shape metals upon which about half of the manufacturing industries are dependent. The state of the art of the machine tools themselves, their control systems and the organization surrounding them largely determine the productivity and competitiveness of engineering industries in general.

The machine tool industry faces two major challenges today. One is that technological change in machine tools has changed character in recent years. After more than a century of evolutionary progress, mainly involving mechanization and improved control of mass production, the main progress in machine tools in the last two decades has involved automation and mechanization of small and medium scale production, largely in connection with the introduction of numerical control and also other aspects of the microelectronic revolution. This change in the character and direction of technological change is forcing profound changes both within the industry and in its relationship with users.

The other problem is that the competitive situation in the world market is changing rapidly, causing severe adjustment problems for most producers. Even though this is an industry in which foreign trade has always been significant, the emergence of new competitors (particularly Japan in numerically controlled machine tools and newly industrialized countries in conventional machine tools) with new strategies and new kinds of specialization has made for radical changes in the competitive situation for most machine tool firms.

One section of the paper deals with the strategies which machine tool firms in the United States and Sweden have chosen to deal with these challenges. This part of the study is based on firm interviews. The paper concludes with some thoughts on the likely results of the present changes for the machine tool industry of tomorrow.

THE MACHINE TOOL INDUSTRY - PROBLEMS AND PROSPECTS IN AN INTERNATIONAL PERSPECTIVE

by Bo Carlsson
Industrial Institute for Economic and Social Research,
Stockholm, Sweden

I. The Problem

The machine tool industry is one of the smallest sectors of manufacturing industry in most industrial countries. In the United States, it represented only three-tenths of one percent of the value of shipments of manufactured goods at the end of the 1970s; in Sweden, it represented about 0.9 percent of value added and 1.0 percent of employment in manufacturing. Even in West Germany, traditionally one of the world's largest producers of machine tools per capita, the share of machine tools in manufacturing employment does not exceed 1.5 percent. (Commission of the European Communities, 1983, p. 9.)

The machine tool industry is very heterogeneous. The output consists of hundreds of different types of products, and the industry is made up of numerous small firms. In 1977, there were 1,343 establishments in the United States machine tool industry, with an average of 62 employees per establishment. In Sweden, there were 129 establishments with an average of 70 employees each. For comparison, the average firm size in West Germany was about 225 employees in 1980. There were 12 plants in West Germany with more than 1,000 employees, while there were 10 in the United States, 7 in the United Kingdom, 2 in France, and none in Sweden. (CEC, p. 11.)

Given the heterogeneity and miniscule size of the industry, why should one study machine tools? There are essentially two reasons. One reason is that the machine tool industry is far more important than its share of industrial value added or employment would indicate. Machine tools are usually defined as power-driven machines (not hand held) that are used to cut, form or shape metal. Thus, machine tools represent the core of production machinery in the whole metalworking industry -- the sector which already contributes about 40 percent of value added in manufacturing in developed industrial countries and which is generally expected to provide a major share of real growth in manufacturing in the coming decades. However, the role of machine tools is not confined to hardware alone; the whole "software", i.e., the organization and control of production machinery, in the metalworking industries is closely linked to the characteristics and use of machine tools. Thus, the machine tool industry may be regarded as a "node" for supplying both production machinery and concepts (both hardware and software) to all metalworking industries, thus playing a crucial role in determining the performance of large sectors of manufacturing in terms of both productivity and international competitiveness. Thus, by studying the development of machine tool technology and its application in industrial processes, it should be possible to get a better understanding of the nature and importance of the production technology in the engineering industry. As numerous recent studies have shown, not least in the automobile industry, there are reasons to suspect that there are significant international differences in production technology and in the organization of production and that these may explain a large part of the international competitiveness of engineering industries.

Another reason to study the machine tool industry is that it presents some interesting problems of its own, worthy of attention by economists. It will be seen that the machine tool industry faces two major challenges today. One is that technological change in machine tools has changed character in recent years. After more than a century of evolutionary progress, mainly involving mechanization and improved control of mass production, the main progress in machine tools in the postwar era has taken quite a different direction. The introduction of numerical control and the whole set of possibilities of electronic guidance and control which are now opening up in connection with the microelectronic revolution are forcing profound changes both within the industry and in its relationship with users.

The other problem is that the competitive situation in the world market is changing very rapidly, causing severe adjustment problems for most producers. Even though this is an industry in which foreign trade has always been significant, the emergence of new competitors (particularly Japan in numerically controlled machine tools and newly industrialized countries in conventional machine tools) with new strategies and new kinds of specialization has made for radical changes in the competitive situation for most machine tool firms in recent years.

The present paper focuses on these latter questions, i.e., the impact of technological change and changes in the character of international competition on the machine tool industry. The more general issue of the interaction between suppliers and users of machine tools, both historically and at the present time, is being studied in a larger international study of machine tool producers and users which is still in progress and of which the present paper is a part.

The paper is organized in the following way. Section II makes a brief review of the historical development of machine tool technology and focuses particularly on the way in which recent development differs from that in earlier periods. Section III examines the changes in the world market for machine tools. Section IV reports on how machine tool producers in Sweden and the United States are trying to deal with these challenges. This section is based on firm interviews. The concluding section summarizes the findings and speculates on the consequences of the present changes for the machine tool industry of tomorrow.

II. Historical Development of Machine Tools

Machine tools have played a fundamental role in industrial growth ever since the Industrial Revolution in England at the end of the eighteenth century. Without Wilkinson's new boring machine, which made it possible to bore the cylinder with greater accuracy, it is unlikely that Watt's steam engine (1775) would have been efficient enough to be of practical value. (Roe, 1916, pp. 1-2.) The discovery in 1784 of the puddling process for making pig iron with coke rather than charcoal (Mantoux, 1961, pp. 293-4) made it possible to produce iron cheaply enough for it to become a major industrial raw material. Up until that time, practically all machinery, or what little of it existed, was made of wood, and nearly all machine tools were geared to work in softer materials. (Roe, pp. 3-4.) In order to make use of iron as a raw material, all kinds of metalworking machines, previously nonexistent, were needed. Thus, in the first several decades of the Industrial Revolution, namely from about 1775 to about 1830, most of the basic machine tools as we know them today were developed. Most of this development took place in England, the only major user of machine tools at that time.

However, in the beginning of the nineteenth century, there were also some significant contributions to the development of machine tools in America. This development is associated with what came to be known as the "American System of Manufactures". It originated with Eli Whitney and his plans for an arms factory in the last few years of the eighteenth century and spread from there to the United States armories and then more widely into manufacturing industry in general. (Pursell, 1967, pp. 399-400.)

The essential idea of the "American System of Manufactures" was the production of interchangeable parts. This required a degree of accuracy and standardization never contemplated before. This was achieved through the introduction into the making of arms of the so-called factory system (which was already in use in making textile machinery). This provided a high degree of specialization and division of labor. But the specialization was carried further than before by breaking down each task into several operations with each worker responsible for only one or two operations. The use of patterns or "jigs" for filing and drilling operations made it possible to achieve a high degree of accuracy even in manual operations; the breakdown of each task into a number of single operations made it relatively easy to mechanize each operation, thereby attaining both an even higher degree of accuracy and the possibility of extending the use of power tools. The system was further enhanced by the invention of several new machine tools, among them the milling and grinding machine.

This "American System" represented a whole new philosophy of manufacturing. It was the diffusion of this system first from arms production into that of clocks, sewing machines, and typewriters and later into farm machinery, locomotives, bicycles, and automobiles which made it possible to mass-produce these goods, thereby making them much cheaper than in Europe and therefore affordable to many more people. Thus, within just a few decades, and well before the end of the nineteenth century, American manufacturing technology in the metalworking industries had surpassed the English level and contributed significantly to the rapid rise in the American standard of living. (Woodbury, 1967, pp. 623-8.)

In the early days of the Industrial Revolution, up until the middle of the nineteenth century, machine tool development was closely linked with the invention and diffusion of industrial machinery in general. It was only after the middle of the century that companies began to specialize in making machine tools; up to that time, the manufacture of machine tools had been carried out more or less ad hoc by the users. (Rosenberg, 1963, pp. 417-422.)

As pointed out earlier, by mid-19th century, most of the machine tools in use today had been developed in their basic form. Since that time, technological change in machine tools has been largely incremental. However, the sum of these incremental changes has been very large indeed, as a comparison of any machine tool today with its 100-year-old ancestor will reveal.

Until the beginning of the 20th century, machine tool development was largely separate for each type of machine tool. Machine tools became larger, heavier, more robust, more accurate, etc., in response to the needs of the particular users in each case. Some machine tools were designed for very high production rates, and there were many examples of mechanization of feeds of individual machines.

But around the turn of the century, the emergence of the automobile industry gave rise to challenges of an entirely new order of magnitude. The automobile is a very complex product even today, and it certainly was complex then in comparison with earlier industrial goods. At the same time, it was a consumer product which faced a potential mass market. Indeed, it was precisely through the introduction of better production methods and machine tools that the automobile became a mass-produced good. It was Henry Ford's relentless efforts to reduce costs which created demands for machines which were vastly more productive and at the same time more accurate than existing machines. Perhaps the most well-known innovation in this connection is the moving assembly line introduced by Ford in 1913. Through this innovation, Ford reduced the typical assembly time needed for his Model T from a day and half to an hour and a half. But this caused problems for the machine shops to supply components as fast as required. Thus, the need arose for machine tools of all kinds with much higher operating rates, with more automatic feed devices and substantially increased accuracy in order to avoid problems further down the production line. Because of the complexity of the product, the machine tools required for its manufacture were of many different kinds: better grinders were required for gears and ball bearings; new machines capable of handling harder and stronger materials were needed, etc. The pressure for higher operating rates, closer tolerances, and higher degrees of mechanization spread to virtually all types of machine tools at the same time. (American Machinist, 1977, pp. E-5-16.) And because of the size of the market, the impact was enormous on both manufacturing technology and on the entire economy. The methods and machine tools which were adopted in the automobile industry then spread gradually to other sectors.

However, the impact of the automobile industry as far as production technology is concerned was not limited to significant improvements in individual machine tools. It also had important consequences for the organization of industrial production; the assembly line required not only better and more productive machine tools but also better ways of controlling them and of coordinating a complex set of activities at a much higher pace than before. Production began to be thought of as a system rather than as a sequence of processes carried out on individual, stand-alone machines. (Wagoner, 1966, pp. 22-3.)

The automobile industry clearly dominated machine tool development during the entire first half of the twentieth century. However, the pace of technological change slowed down during the Depression, and the extremely low rate of investment held back the diffusion of new machines. There were only two major new technologies with respect to machine tools that came out of the interwar period. One was cemented carbide as a tool material, substantially harder and longer lasting than previous tool materials and facilitating metal cutting at speeds unheard of before. However, the economic impact of cemented carbide tools was not significant until World War II in the United States and after the war in Europe.

The other major machine tool technology of the interwar period was the transfer machine. Transfer machines consist of a number of work stations, each for a separate operation such as drilling or milling, combined into a single machine with an integral system of transferring the workpieces from one work station to the next. A typical application of a transfer machine is a series of finishing operations on a wheel housing or an engine block. The transfer line principle had been applied as early as 1888 in watch making, and in 1924 it was used in England to finish cylinder blocks. But the first true transfer machine was built in the United States in 1929 for the manufacture of engines and became standard practice in the automobile industry in the 1930s. (Bright, 1967, pp. 643-4.)

As American industry geared up for wartime production and invested heavily in expanded capacity, one of the results was the greatest renewal ever of American manufacturing facilities, including the stock of machine tools. (American Machinist, pp. G-1-8.) These World War II production facilities have played a major role in American manufacturing industry even to this day.

Another lasting impact of World War II on production technology was the emergence of the aircraft industry as a major user of machine tools. The five- to ten-fold increase in aircraft production necessitated by the war brought new production problems but also new ideas, among them the application of production knowhow from the auto industry to the manufacture of airplanes. Because of the increase in capital equipment required, the special production problems involved, and the high priority assigned to the expansion of aircraft production, the aircraft industry became the dominating influence on technological change in machine tools during World War II, a position which it has since retained (jointly, since the late 1950s, with the space industry).

When the war ended and manufacturing industries returned to civilian production, the production methods and tools used during the war were applied to civilian products. The higher speeds and greater rigidity of machine tools required by the new tool materials also put increased demands on the motive power of machine tools: the average horsepower of machine tools rose from 11.9 in 1938 to 23.4 in 1948 and 50 by 1958, i.e., the horsepower per machine doubled every ten years. (Sonny, 1971, p. 77.)

Another important development was increased use of mechanization. As we have seen, mechanization had been an important part of technological change in machine tools since the end of the 19th century, particularly in the automobile industry, with Ford as the technological leader. Now the idea of automation through mechanical handling devices between transfer machines was introduced. The first large-scale application of automation was Ford's Cleveland engine plant beginning operation in 1950. (American Machinist, pp. G-6-8.)

Automation of industrial processes through mechanical devices for handling the transfer of workpieces from one machine or work station to the next, along with improved control mechanisms for both materials handling and the process itself, is certainly one of the two most important developments in production technology in the postwar period. The other is numerical control and the use of electronic devices in general instead of mechanical ones.

In 1948, John T. Parsons, an engineer and industrialist, saw the blueprints of a proposed Lockheed airplane to be produced for the United States Air Force. The aircraft featured a new structural concept, namely integrally stiffened wings to be achieved by hollowing out, through milling, of certain profiles in thick aluminum slabs -- rather than by riveting a metal skin to a frame of individual ribs in the conventional manner. The problem was how to actually accomplish this to the exact specification required. Removing too much material, or removing it in the wrong places, would make the wing structurally unsound, resulting in wing failure and waste of resources; removing too little material would make the wing too heavy, and the plane would not fly or would be too fuel inefficient.

Parsons interested the Air Force in the idea of applying a method he had used earlier in making helicopter blades -- calculating airfoil coordinates on a crude computer and feeding these data points to a boring machine. The Air Force bought the idea, and this led to a series of research projects at the Massachusetts Institute of Technology, beginning in 1949. The first commercial applications began to appear in 1952. At the Chicago machine tool show in 1955, there were two numerically controlled lathes on display. By 1958, the first numerically controlled multi-function machine capable of automatically swapping the cutting tools in its spindle was introduced: a machining center which was in effect a combination of a milling machine, a boring machine, and a drilling machine. It could perform a series of such operations by automatically changing the tools in the spindle instead of shifting the part from one specialized machine to another. (American Machinist, pp. G-6-16.)

One of the basic advantages of numerical control is that it makes it possible to produce highly complex parts with a high degree of accuracy, and that an NC machine is relatively easy to program. Its programmability makes it particularly suitable for short production runs; it is ideal for manufacture of a variety of parts, each of which is produced in small batches. For large volume production (say, several hundred thousand units of a single item), it is usually cheaper to use specially designed (but inflexible) machines or series of machines (transfer machines). For single items or for very small production lots it is still cheaper to use conventional machine tools in combination with skilled labor. However, with computer-aided design and computer-aided manufacturing devices, the possibility arises of converting information directly from drawings into machine instructions. When this possibility is converted into actual practice -- a process which has only just begun -- it may be cheaper, especially in cases of highly complex parts, to use NC rather than conventional machine tools. An important reason for the economic significance, both potential and actual, of numerically controlled machine tools, is that perhaps two-thirds of the products made in the engineering industries are manufactured in batches of a size suitable for NC machine tools.

Beyond this, the advantages of numerically controlled machine tools are largely of an organizational nature. The metal-cutting operations which they perform are not essentially different from those performed in other machines. But the possibility of much closer interaction between design and production which they offer, the capability of making rapid and frequent design changes, the ability to accept workpieces of widely varying size and shape (whereas a transfer line is extremely limited in this regard) gives them a flexibility not available with earlier existing machinery. "The day of black automobiles and white refrigerators is long over. The name of the game today is product diversification and fast response to the changing needs of the marketplace. Mass production, as we have known it, is not compatible with these demands." (American Machinist, p. I-1.)

Thus, the fundamental difference between numerical control and the machine tool technologies that preceded it is that now for the first time the possibility has arisen of automating small and medium scale production. Virtually all the technological change in machine tools before NC was directed at extending the scope, increasing the productivity and improving the accuracy of mass production. Numerical control makes it possible to apply industrial machinery and production methods to activities which were previously essentially of a handicraft nature.

This also has a profound impact on the structure of the machine tool industry. Before numerical control, there were essentially only two kinds of machine tool firms: those producing conventional machine tools (usually only three or four basic types each) and those producing transfer machines. For conventional machine tool producers it was sufficient to know all about the particular types of operations of the machine tools they manufactured -- milling, turning, etc. -- and their applications by their customers. Manufacturers of special machines and transfer-type machines, however, had to know a great deal about the manufacturing process of their customers in order to be able to design the proper equipment. But for the most part, customers were able to supply the machine tool builder detailed specifications of the process involved, the sequence of the operations to be performed, the materials handling devices required, etc. But with the introduction of numerical control, a new situation arose. Initially, NC machines broke into conventional markets only; it is only in the last few years that the transfer machine market has been affected. Thus, conventional machine tool firms had to decide what strategy to choose to deal with numerical control, i.e., whether to enter NC production or formulate alternative strategies. In addition, as NC machine tools have become more and more sophisticated, computerized, and integrable into larger systems, the demand for a new type of interaction between users and suppliers of machine tools has arisen, with neither the user nor the supplier having enough knowhow to design the systems that are needed. These are the problems to which we will turn in Section IV of this paper.

III. Changes in the World Market

The machine tool industry is hardly a spectacular growth industry, although as will be explained presently, it is difficult to say exactly what the growth rate has been. This has to do with the index number problem and is illustrated to some extent in Figure 1.[1] According to

---

[1] I am indebted to Robert E. Lipsey for having brought the problems of output measurement to my attention.

the figure, the number of metal-cutting machine tools produced in the United States rose from about 200,000 units per year in the late 1950s to around 350,000 units in the late 1970s. But since we know that a significant number of machine tools, and a growing share of them, have been numerically controlled, and since all machine tools whether NC or conventional have tended to become larger, more robust, more accurate, more complicated, etc., over time, the number of machine tools produced would seriously underrepresent output at the end of the period. On the other hand, measuring output in terms of current prices would overrepresent the change in output because of the problem of inflation. Using the value of output in constant prices should in principle be better than these alternatives -- but it raises the question of just how good the underlying price index is with respect to taking quality changes into account. As indicated in the figure, by deflating the value of output by the producer price index for machine tools, one is led to the conclusion that there has been no increase at all in machine tool output in the United States since the late 1950s. But by taking late-year price weights, one runs the risk of deflating away the quality changes, thus ending up with an underestimate of actual output growth.

The problem is further illustrated by the following calculation. The 5-year moving average growth rate for the period 1959-63 to 1976-80 for the number of metal-cutting machine tools produced in the United States (shown in Figure 1) is 3.0 percent per year. The corresponding rate for output measured in 1980 prices is 2.6 percent. The fact that output measured in constant prices rose more slowly than the number of machine tools produced may be partly due to slight differences in the original data sources (NMTBA and U.S. Department of Commerce, respectively) - but it is difficult to escape the conclusion that both measures probably seriously underestimate the actual increase in the industry's output. In order to estimate the magnitude of this error, a separate investigation would be required.

The problem of correct measurement of output is compounded at the international level: besides the price index problem there is also the problem of making correct international price comparisons. As Kravis et al. have shown, quantity indexes for per capita commodity consumption based on purchasing power parity comparisons may differ by as much as 30 percent from similar indexes based on price conversion at official exchange rates even in developed industrial countries. (Kravis et al., 1982, p. 22.) However, even though one would like to take these problems into account, the limited availability of data makes it practically impossible to do so. Thus, the data presented below should be interpreted with this in mind, although it does not seem as though the valuation problems are serious enough to affect the conclusions drawn.

Total world production, deflated by the United States producer price index for machine tools, grew by an average of 2.9 percent per year during the period 1955-80. (See Table 1.) However, growth was very unevenly distributed among countries: Japanese machine tool production increased by 17 percent per year while that in Britain remained almost constant and that in the United States actually fell. In the United States, shipments of metal-cutting machine tools, measured in thousands of units, were barely larger at the end of the 1970s than they were at their war-time peak in 1942.

Besides slow growth (or perhaps none at all), another characteristic of the machine tool industry is the volatility of output. This is true especially for the United States (see Figure 1), where, e.g., domestic shipments of metal-cutting machine tools were 2.5 times larger (in constant prices) in 1968 than they were in 1971. But in countries more heavily involved in international trade, fluctuations in output seem to have been a great deal smaller. The volatility of demand for machine tools, of course, has to do with the fact that machine tools are used primarily in investment goods producing industries.

Historically, the United States has been by far the largest producer of machine tools, with Germany in second place. In 1955, about 40 percent of the world's machine tools were produced in the United States; by 1980, that share had been reduced to less than 20 percent.

At the same time West German machine tool production had increased so that it exceeded the American level during most of the 1970s. By 1980, Japan had reached about 80 percent of the American and West German level, having been less than half as large in 1975. See Table 1.

The changing international distribution of world production of machine tools is reflected also in changing trade shares. As shown in Table 2, the traditional dominance of Germany has been reduced in recent years, particularly by Japan (in spite of the fact that the share of German production exported has increased from about half to about two-thirds in the last 20 years). But at the same time, an internationalization process has taken place; the combined world market share of the four large exporters included in the table has been reduced from 90 percent before World War II to just over 50 percent today. Whereas in the mid-1960s about 25 percent of world production of machine tools was exported, by 1980 that share had increased to 43 percent. In the United States, the share of exports in total shipments remained constant at 12 percent between the periods 1956-60 and 1976-80, while imports rose from 6 percent of U.S. machine tool consumption in 1958 to nearly 24 percent in 1980. As shown in Figure 2, this implies that the United States went from a position of a strong net exporter to one of a substantial importer.

By contrast, Sweden, traditionally a net importer of machine tools, became a net exporter for a few years in the late 1970s. However, this was due primarily to a sharp dip in domestic consumption, reflected also in domestic production. See Figure 3. Over the period 1960-82, Swedish machine tool exports as a share of domestic production rose from just over 50 percent to nearly 80 percent. At the same time, imports as a share of apparent consumption increased from 60 percent to almost 80 percent.

Not only has the degree of internationalization of trade in machine tools increased dramatically in the last two decades; the composition of trade with respect to country of origin has also changed. (Cf. Table 2.) In the United States, for example, Japan has recently overtaken West Germany as the largest foreign supplier of machine tools. See

Figure 4. The United Kingdom still defends its third place but is now threatened by Taiwan, which has gone from nowhere into the position as the fourth largest exporter to the United States.

In Sweden, West Germany is still the largest foreign supplier, with Japan in second place. The previously strong positions of the United States and the United Kingdom have been surpassed also by Switzerland and Italy. See Figure 5.

Thus, the machine tool market has been rapidly internationalized in recent years. Certain countries have seen their competitive positions strengthened while others have seen theirs weakened. As in many other areas, Japan has increased her share of world production and trade in machine tools, with the United States and Western Europe being the main losers of market shares. Therefore, one of the greatest challenges facing machine tool firms in these countries today is how to deal with the Japanese competition. What makes the challenge especially tough is that the Japanese competition is not spread over the whole spectrum of machine tools but is rather concentrated to the most dynamic segment, namely numerically controlled machine tools. In 1980, over 50 percent of Japanese machine tool exports consisted of NC machine tools; of all Japanese NC machine tool exports, NC lathes and machining centers made up 90 percent. (CEC, Annex 2b.)

While the technological breakthrough of numerical control came during the 1950s, the commercial breakthrough was delayed until the late 1960s. The United States took an early lead, followed by Sweden and Great Britain, with West Germany somewhat behind. (Nabseth & Ray, 1974, p. 55.) By the late 1960s, NC machine tools represented about 20 percent of the total production of machine tools in the United States. Cf. Table 3. Then the share actually fell during the first half of the 1970s (in connection with a sharp decline in total machine tool production -- cf. Figure 1) and has only very recently exceeded that in 1968. But until the latter half of the 1970s, the United States was unquestionably the leading producer of NC machine tools. The NC shares of the value of machine tool output were significantly lower in

Sweden and the United Kingdom (and presumably also in Japan and West Germany, although no figures are available). But in 1977, the number of NC machine tools produced in Japan surpassed that in the United States; by 1980, the number of NC machine tools produced in Japan was nearly three times as great as that in the U.S., and the value of NC shipments also exceeded that in the U.S. The high degree of product specialization of Japanese production, in combination with the strong Japanese export orientation, meant that close to 50 percent (by value) of the NC lathes and machining centers sold in the United States in 1980 were Japanese; the Japanese shares of the market in the European Economic Community were 19 percent in NC lathes and 13 percent in machining centers. (CEC, p. 24.)

There are several implications of this, the most obvious being the phenomenal rate of Japanese growth in the most rapidly growing segments of the machine tool market in the last few years. This phenomenal Japanese success begs the question of what its causes might be. Although it does not fall within the scope of the present study to make a detailed investigation of the "secrets" behind the Japanese success in machine tools -- a topic which would clearly be suitable for future research and worthy of a study of its own -- there are many hypotheses which have been put forward in the literature and also in the interviews with machine tool firms in the United States and Sweden reported on in the next section. The tentative picture that emerges is the following:

1) The Japanese firms which are successful in international markets have chosen strategies which are well adapted to the world market. Some of the main elements of these company strategies are:

a) Concentration on developing and producing machines for mass markets. This means developing machines for average users rather than for specialized needs, i.e., general-purpose, standardized but versatile machines. An essential part of this strategy of mass production is that of extending the applicability and improving the reliability of numerically controlled machines, thus creating an entirely new market (but largely at the expense of conventional machines). This has characteristically been done by first developing small and relatively cheap machines and then gradually shifting into larger, more sophisticated machines. Large volume production has enabled the Japanese to reduce their manufacturing costs to levels far (often 30-50 percent) below those in American or European companies producing similar machines.

b) Making thorough market investigations, both domestically and abroad, and responding to actual and potential market demand. An important aspect of this is timing and ensuring quick delivery.[1]

c) Specialization in a narrower product range than Western competitors, e.g. on NC lathes and machining centers.

2) In addition to firm strategies, there are some elements of industry structure and organization which seem important. Some of these may have come about "spontaneously", while others may be the result of policies conducted by the Japanese Ministry of International Trade and Industry (MITI). It is difficult to assess how much should be attributed to MITI and how much to market processes. But it is clear that MITI has played quite an active role in the machine tool industry as in many other sectors of Japanese industry. According to information obtained from the National Machine Tool Builders' Association in the United States and the Commission of the European Communities, MITI's policies have been designed to modernize and increase production capacity in the industry, promote concentration and specialization in the sector, promote cooperation among firms through the formation of a cartel and collaborative research institutions, stimulate product standardization, further the manufacture of NC machine tools, fix production and price targets, grant a host of

---

1 The big wave of Japanese entry into the United States NC machine tool market occurred in the recent investment boom, starting in 1977 and ending in 1981, when the American automotive and aircraft manufacturers were retooling for smaller, more fuel efficient vehicles. This investment boom kept American machine tool manufacturers so busy with existing product lines that delivery times sometimes reached 2 years. Under such circumstances, off-the-shelf delivery was a very compelling argument for Japanese machines.

financial supports and incentives (tax benefits, concessionary loans and grants, etc.), and support domestic demand through allowances for purchasing automatic equipment.

3) One of the features of the Japanese machine tool industry is the development of a strong electronic capability in the form of the Fanuc company which delivers electronic equipment, especially NC controllers, to virtually all Japanese machine tool manufacturers -- as opposed to several companies in each country in the West, and even separate efforts in individual machine tool firms.

4) Some (but far from all) of the larger Japanese machine tool builders are integrated with large industrial concerns. Put more generally, many Japanese firms have close collaboration with highly competent users of machine tools, whether owned by them or not.

5) The Japanese machine tool industry appears to be far more concentrated and to consist of much larger firms than in Western countries. See Table 4. According to the table, 20-26 percent of the employees in the machine tool industry in the United States, West Germany, and the United Kingdom are employed in firms with more than 1,000 employees, and a somewhat smaller share in Italy, whereas in Japan over 50 percent of employment is in firms with more than 1,000 employees.

Thus, looked at from the aggregate industry point of view, it would appear that the problems posed by technological change and new competitors merge into one: the Japanese invasion of the NC market. But as we shall see in the next section, such a conclusion is premature and would probably result in erroneous policy recommendations.

IV. Strategies to Deal with the Technological and Market Challenges

In Section II above, it was concluded that one of the major challenges facing the machine tool industry today is the fundamental change in the philosophy and organization of manufacturing resulting from the application of numerically controlled machine tools. When NC machine tools are integrated into larger cells or systems, possibilities arise of automating production at small and medium scale, an area where automation and mechanization have not generally been contemplated previously. For machine tool producers, this has meant that the need has arisen to decide whether or not to go into numerical control and, if NC is adopted, to what extent to acquire knowledge about the technology in order to be able to assist customers in their particular applications.

In Section III it was shown that in addition to this technological challenge, the market situation for machine tool firms has changed markedly in recent years: slow growth, rapid internationalization (meaning much more international competition), and the emergence of tough new competitors, especially Japan.

How do these challenges appear to individual firms, and how do they try to deal with them? These are the questions with which we are concerned in this section. Because of the heterogeneity of the industry, it is necessary to go beyond the macro (industry) level in order to understand what is happening in the industry. Therefore, the analysis is based on interviews with machine tool builders in the United States and Sweden carried out within the larger study of which the present paper constitutes a part. It should also be pointed out that at the same time as individual firm interviews open up possibilities of obtaining a much richer and more detailed view of the industry's problems, they also pose difficulties in the presentation of the results, particularly in a brief paper: for reasons of both space and confidentiality, it is not possible to present the results in detail. Yet, generalizations based on the interview results often do not do justice to the material and may even be misleading; there is always the problem of representativity. The following pages represent an attempt to strike a balance between these two positions.

The results reported here deal with only a portion of the interviews; a more complete and thorough presentation and evaluation of the results will be carried out in the larger study which is still in progress.

IV.1 Interview Coverage

The Swedish machine tool interviews covered six firms representing most of the types of machine tools manufactured in Sweden. These firms also covered the whole size spectrum of firms in the Swedish machine tool industry, ranging from $2 million to around $50 million in sales and from less than 50 to over 500 employees. The share of output exported varied between 30 and 75 percent, and the share of output consisting of numerically controlled (NC) machine tools varied between 0 and 100 percent.

For the six United States firms interviewed, the sales volume varied between $10 million and nearly $1,000 million, with employment varying between over 100 and nearly 14,000. The products covered in the American interviews were both large and small transfer machines, automatic assembly machines, NC lathes, NC machining centers, NC aerospace profilers, NC grinders, broaching machines, precision spindles and slides, and presses (both mechanical and hydraulic). As could be expected, the export shares of the American firms were lower than those reported for Swedish firms, ranging between 0 and 29 percent. The share of output represented by numerically controlled machine tools varied between essentially 0 and nearly 100 percent.

As is typical for the industry, the firms interviewed here generally produce one or two, occasionally three or four main types of machines; no firm in the whole industry produces all types of machines. Within each product category, producers tend to specialize in a certain size range, particular types of application, degree of precision, ancillary equipment, etc. There are actually hundreds of products categorized as machine tools. For these reasons, the concentration ratios normally computed for whole sectors make little sense in this industry. For example, in 1973, the largest four producers in the United States accounted for only 22 percent of sales in metal-cutting machine tools and 18 percent in metal-forming machine tools, while in Germany the three largest firms accounted for only 7 percent of the industry's turnover. (Daly & Jones, 1980, p. 56.)

But in individual products, these ratios are often considerably higher. Thus, even though there are numerous firms in the industry, each one typically competes with only a handful of other firms in each product line. But since, as we shall see, the competitive situation is quite fluid, and since the threat of new entry by foreign competitors is substantial in many areas, the degree of concentration in this industry can hardly be a cause of public policy concern.

IV.2 The Competitive Situation for Individual Firms

The impression one gets from studying Figure 3 is that the bulk of apparent consumption (domestic production minus exports plus imports) of machine tools in Sweden consists of imported machine tools. In fact, the share of imports in apparent consumption has increased from 60-65 percent in the early 1960s to around 80 percent in 1980. But the interviews reveal that for individual machine tool firms, the situation is even more extreme.

In conventional machine tools, the competitors of Swedish firms are most often other small firms in Western Europe and only seldom other Swedish firms. There is also rapidly increasing competition from firms in developing countries - something which is not yet apparent in the aggregate statistics cited in the previous section. In 1980, exports from non-OECD, non-COMECON countries constituted only about 3 percent of total world exports of machine tools. (Calculated on the basis of NMTBA, 1981, p. 165.) But for certain types of machine tools, particularly conventional ones, and for producers exposed to a great deal of foreign competition in both domestic and foreign markets, the threat of competition from developing countries is very real.

In the United States, the most important competition in conventional machine tools comes from other American firms but lately also some Far Eastern firms. However, there is little or no Japanese competition in conventional machine tools (this is true in Sweden also); the Japanese left that market, at least as far as exports to other industrialized countries are concerned, about 10 years ago, and have since concentrated on numerically controlled machine tools. As far as NC machine tools are concerned, therefore, Japanese firms figure prominently among the competitors of both American and Swedish firms. But whereas in the United States most non-Japanese competitors are domestic, in Sweden they are primarily West European and to some extent American firms.

What have been the most important changes in the competitive situation of machine tool firms over the past two decades? The typical answer given by Swedish conventional machine tool firms is that the market has begun to shrink in recent years because of competition from numerically controlled machine tools and because of the low investment level in West European industry. Also, West European competitors have largely been replaced by firms in the developing countries. American conventional machine tool builders typically respond that until the last couple of years, they have had practically no foreign competition, and that it is only very recently that the market has started to shrink because of competition from numerical control.

If NC machine tool manufacturers are asked the same question, Swedish firms answer that whereas ten years ago the most important competitors were West German, they are now Japanese. American firms respond that up until five years ago, there was virtually no foreign competition except in some special machines which did not really compete with domestic machines. Now, international competition, especially from the Japanese, is the most prominent and worrisome feature, especially in the most rapidly growing product lines.

Thus, the interview results confirm and strengthen the finding at the macro level that the nature of competition has changed drastically in recent years. There is little doubt that this is one of the strongest dynamic forces influencing both the industry and the technology of machine tools today. The essence of the new element of competition is unpredictability: much less is known about the new competitors now emerging than about old competitors who have been around for decades. The reaction to a given change in the environment is much easier to predict in the case of firms whose management, overall strategy, technology, cost structure etc., are known than in the case where these are not known or are known only to differ sharply from those of the own firm. The machine tool companies interviewed in this study seem, on the whole, to know a great deal about their domestic or Western competitors but very little about their Japanese and other Far Eastern competitors.[1]

IV.3 Main Competitive Threats - and Strategies to Deal with Them

What, then, do machine tool firms perceive to be the main threats against them over the next ten years, and how do they respond to these threats?

In conventional machine tools, the main threat is seen as coming from potential massive entry by manufacturers in developing countries. But there is also a technological threat: the process of even smaller, cheaper and yet more versatile NC machines taking over markets from conventional machines will continue, probably at an increasing rate. One example of a strategy to deal with this is to redesign existing products in such a way that they consist of a set of standardized modules, while at the same time moving gradually into more sophisticated machines, both special machines and NC machines. These standardized components or modules can be used interchangeably. This makes it possible to put together a more or less customized machine from a set of standardized modules. It also reduces the number of parts to be manufactured and therefore

---

1 For a discussion of the relationship between unpredictability of micro behavior and macro performance in terms of dynamic efficiency, see Klein (1977), especially Chapter 6. I am indebted to professor Klein for many of the ideas underlying this study and particularly the firm interviews, some of which we have carried out jointly.

lengthens production runs and cuts production costs while at the same time maintaining or even increasing the assortment and versatility of the products offered to customers. By moving into special (custom-built) machines which require much more engineering and close cooperation with customers than standard machines, companies can move into areas with much less competition, especially from firms in less developed countries. On the other hand, these market segments may be much smaller and grow more slowly than the market for standard machines.

As far as NC machines are concerned, the Asian (so far primarily Japanese) threat is seen as the most immediate and the most difficult to deal with. In the longer term there is also a technological threat arising from increased use of nonmetallic materials, new ways of cutting metal (laser), better molding or forming techniques which may eliminate machining altogether in some cases, etc. Thus, it is interesting to note that the technological threat which NC machine tool producers perceive is not the systems problem mentioned in Section II (that of integrating NC machine tools into larger manufacturing systems). Of course, this is not to say that they are not concerned about their systems capability. They do view this as a problem in their relations with customers, but at the same time as something which their competitors also face. These relations are stressed as crucial in developing new products. There is a general consensus that the user side is the main driving force in technological change in this industry. Therefore, and this is perhaps indicative of the nature of the problem, the systems capability problem is typically raised by the users, not by machine tool builders. At least that has been the experience in these interviews. This is reflected also in the content of the user side interviews (reported on elsewhere). Nevertheless, some firms try harder than others, as a matter of strategy, to find solutions to their customers' production problems rather than just sell machines.

The responses to the Japanese challenge vary across the board: from simply abandoning the product lines competing with the Japanese machines to meeting them head on with exactly the same types of machines. In between these extremes there are numerous opportunities which are being exploited, primarily involving larger, more expensive, and more customized machines which require substantially more engineering. The one area in which the Japanese appear not to have been successful, at least so far and largely as a result of conscious strategy choice, is in this type of machine. Other strategies involve trying to stay a notch or two ahead of the Japanese in terms of quality: accuracy, cutting speeds, feeding and unloading devices, etc.

As far as the long-term technological threat to machine tools is concerned, the companies that go beyond simply recognizing the threat and are actually doing something about it tend to be larger, more diversified firms with business in areas besides machine tools. There may, indeed, be little or nothing the machine tool division per se within these companies can do. In companies specialized entirely in machine tools, there seem to be few attempts to diversify out of the industry. The larger, more diversified firms may therefore have a definite long-term advantage in this regard. This also seems to be true with regard to systems capability.

V Conclusion and Prospects for the Future

History indicates that knowhow with respect to the use of machine tools is an important determinant of industrial productivity and competitiveness. And if it is true, as the evidence in this paper seems to indicate, that the direction of technological change has changed in recent years so that the relationship between machine tool supplier and user has become even closer than before, the implication is that the health and survival of machine tool industry in close proximity to major metalworking industries is crucial. However, to try to achieve this through protection of domestic industry -- and there are many sentiments voiced in this direction today throughout both America and Europe -- seems doomed from the start; there is probably no better way to ensure technological backwardness of domestic firms than to protect them from foreign competition.

The strategic choices of machine tool firms are illustrated in Figure 6. For conventional machine tool makers, the choice is between staying in conventional products, perhaps in combination with moving into more highly engineered, specially designed (custom-built) machines -- represented in the figure by the shaded area between standard machine tool producers and users -- and moving into numerically controlled machines. It is likely that there will continue to be a market for conventional machine tools for a good many years to come. After all, even after more than 20 years of numerical control, the NC share of the United States machine tool market barely exceeds one-quarter. But the non-NC market may dwindle faster than heretofore, and increased market penetration by new competitors in developing countries is likely, particularly in export markets. The market for existing conventional machine tool makers who choose to remain is therefore likely to stagnate or shrink. Yet, this may still be a lucrative market for highly innovative, engineering oriented firms.

For NC machine tool builders, the choice is between going further into engineering and special design of existing product lines, on the one hand, and going into systems on the other. The former requires more mechanical, the latter more electronic knowhow. Although the demand for both of these types of changes is great and offers a great growth potential, these very prospects are also likely to trigger new entry, particularly by conventional tool makers and by new firms in developing countries.

The further machine tool builders venture into systems or engineering, the more likely they are to encounter new kinds of competition. Computer companies are in a particularly good position to enter into manufacturing systems; and the more specially designed the equipment is, the closer one gets to the specialty of the customer. It may well be that the best way to ensure the survival of a healthy and technologically advanced machine tool industry is for machine tool users to take the initiative and offer more of a challenge -- both a carrot in the form of more collaboration and a stick in the form of potential entry into the market. But these are issues for further study, along with the question of what the role, if any, of public policy should be in the continued restructuring of the machine tool industry.

The results of this study show that there is not just one strategy likely to deal successfully with the challenges facing the industry today but that there are numerous strategies that are feasible. The study also shows that success or failure does not necessarily depend on firm size, adoption or non-adoption of numerical control, or the type of specialization chosen. What seems to be most important is that some kind of sound choice of business strategy be made by firms -- and what is "sound" does not lend itself to generalization but depends on the circumstances in each case -- and then adhered to through good management practices. To the extent that government policies can facilitate such "sound" choices and increase the probability of their success, they are clearly desirable.

Table 1 **Production of Machine Tools in Certain Countries, 1955-80**

Millions US $

	Total world production	United States	Soviet Union	West Germany	United Kingdom	Japan	Sweden	U.S. producer price index, machine tools
1955	2 432	984	336	343	211	14	..	18.8
1960	3 285	788	602	563	267	125	..	24.3
1965	5 411	1 445[a]	795[a]	740[a]	400[a]	260[a]	..	27.8
1970	8 268	1 535[a]	1 070[a]	1 395[a]	445[a]	1 090[a]	64	35.8
1975	13 640	2 480	1 964	2 345	616	1 089	166	56.6
1980	26 517	4 802	3 115	4 693	1 190	3 817	234	100.0
Growth rate in constant prices 1955-80, %	2.9	-0.3	2.2	3.9	0.2	17.0	2.7	

[a] Refers to shipments rather than production.

[b] 1970-80 only.

Sources: 1955-60: Secretariat of the United Nations Centre for Industrial Development, "World Machine Tool Production with Special Reference to Developing Countries", 1965, p. 39.

1965-80: NMTBA, Economic Handbook, various issues; Föreningen Svenska Verktygsmaskintillverkare.

Table 2 **Share of World Exports in Machine Tools: Germany, United States, United Kingdom and Japan, 1913-80**
Percentages

	Germany	United States	United Kingdom	Japan
1913	48	33	12	N.A.
1924	30	35	14	N.A.
1937	48	35	7	N.A.
1955	35	30	12	N.A.
1965	28	17	13[a]	3
1975	32	10	6[a]	6
1980	26	7	6	13

[a] Figure obtained from Daly and Jones.

Sources: 1913-1955: Daly and Jones, p. 53.
1965-1980: NMTBA, Economic Handbook various issues.

Table 3 **Production of Machine Tools (total) and Numerically Controlled Machine Tools in the United States, Japan, Sweden and the United Kingdom, 1968-80**

	United States				Japan				Sweden				United Kingdom
Year	Total MT Shipments $ million	NC Machine tools Shipments $ million	NC Machine tools Shipments number	% NC by value	Total MT Shipments $ million	NC Machine tools Shipments $ million	NC Machine tools Shipments number	% NC by value	Total MT Shipments $ million	NC Machine Tools Shipments $ million	NC Machine Tools Shipments number	% NC by value	% NC by value
1968	1 723	354	2 917	20.5	650								7.8
1969	1 692	294	2 376	17.4	862				51.6	4.9	733	9.6	8.5
1970	1 552	209	1 901	13.5	1 109				64.3	4.9	688	7.7	7.9
1971	1 058	153	1 238	14.5	952				78.8	9.0	881	11.5	9.6
1972	1 269	170	1 630	13.4	892				84.7	8.1	566	9.5	6.0
1973	1 788	272	2 685	15.2	1 477				101.9	13.8	265	13.5	6.5
1974	2 166	379	4 210	17.5	1 650	201	3 040	12.2	125.9	17.7	322	14.1	6.3
1975	2 406	505	4 136	21.0	1 060	134	2 182	12.7	165.6	26.8	387	16.2	7.3
1976	2 178	501	3 856	23.0	1 059	171	3 286	16.2	176.2	45.4	362	25.8	7.2
1977	2 453	497	4 482	20.2	1 609	300	5 436	18.6	156.3	40.6	333	26.0	8.3
1978	3 143	649	5 688	20.7	2 372	510	7 336	21.5	156.5	38.9	319	24.8	10.6
1979	4 064	932	7 178	22.9	2 896	937	14 317	32.4	209.5	59.2	386	28.3	11.4
1980	4 801	1 256	8 856	26.2	3 830	1 498	22 069	39.1	233.9	67.9	401	29.0	..

Sources: NMTBA, Economic Handbook of the Machine Tool Industry 1981-1982, pp. 93, 100-102, 194, 198; Föreningen Svenska Verktygsmaskintillverkare; Anne Daly, "Government Support for Innovation in the British Machine Tool Industry: A Case Study", in C. Carter (ed.), Industrial Policy and Innovation, (London: Heinemann Educational Books), 1981, p. 61.

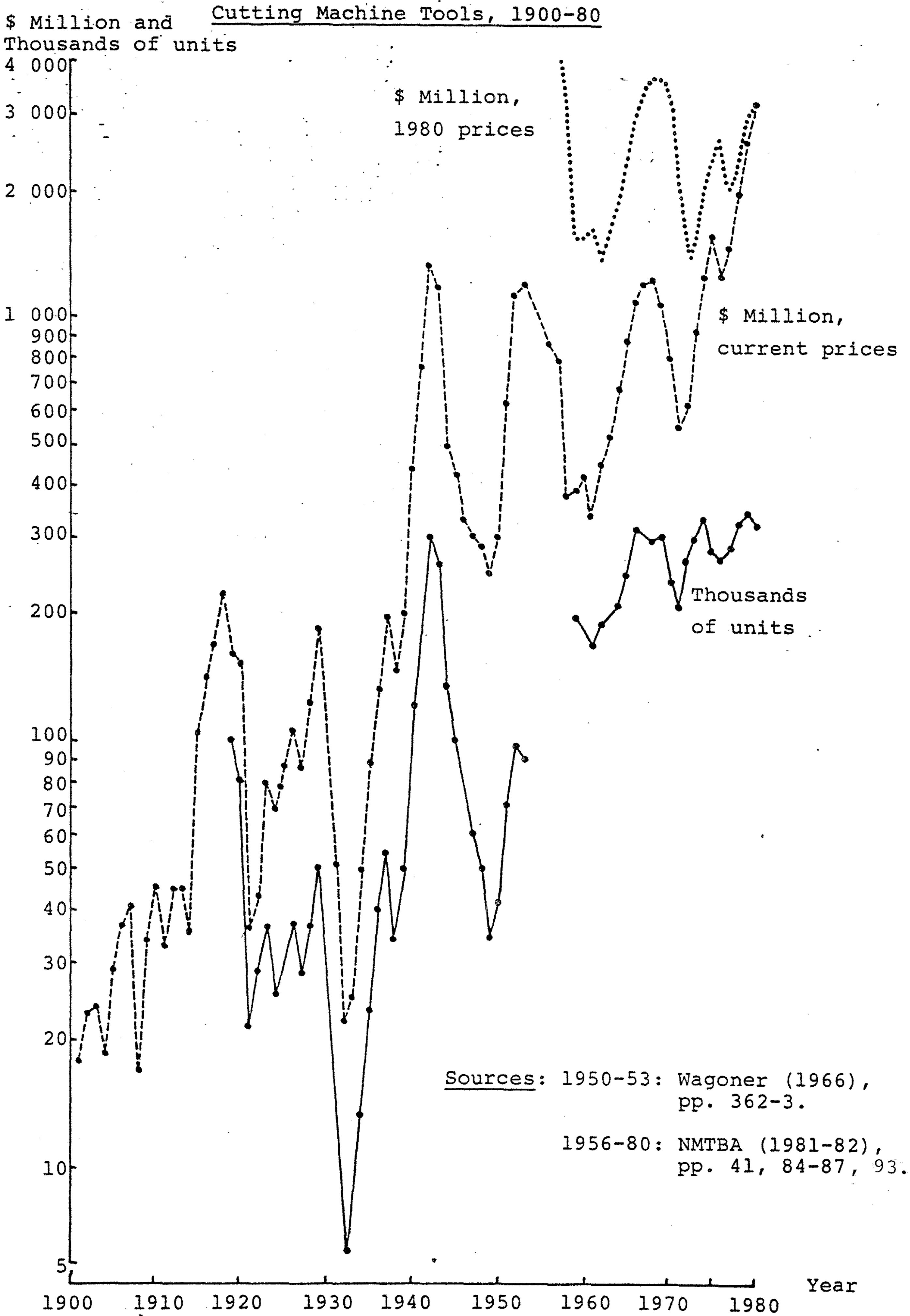
Table 4 **Concentration in the Machine Tool Industry in West Germany, Italy, the United Kingdom, the USA and Japan, 1980.**

Firms with a workforce of over 1,000

	% Firms	% Employees	% Production
West Germany	3.6	23.6	22.0
Italy	0.2	15.9	16.0
United Kingdom	1.7	25.8	25.5
USA	0.7	20.0	N.A.
Japan	23.0	50.7	53.1

Source: CEC, Annex 8.

Figure 1 United States Domestic Shipments of Metal Cutting Machine Tools, 1900-80

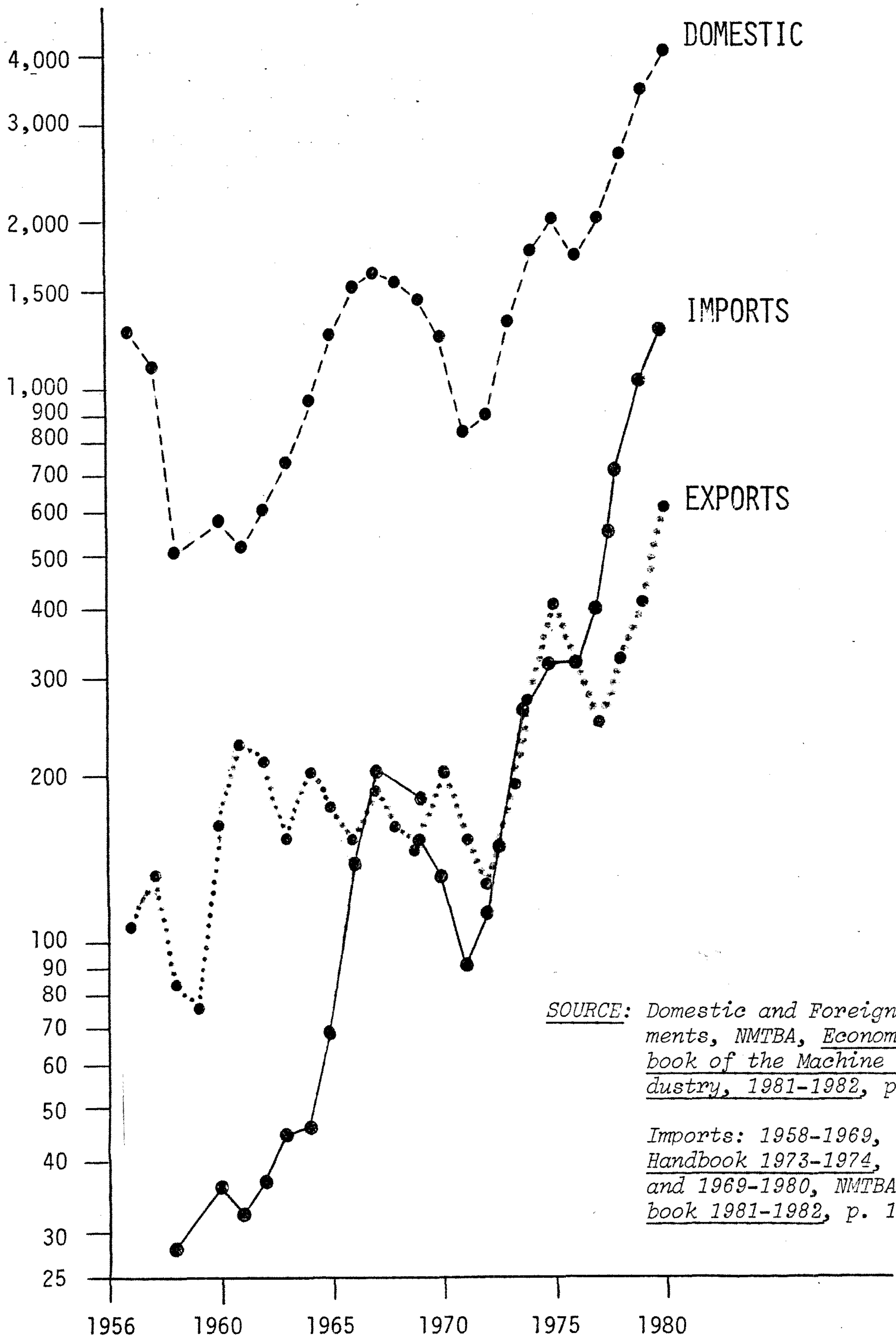


Sources: 1950-53: Wagoner (1966), pp. 362-3.

1956-80: NMTBA (1981-82), pp. 41, 84-87, 93.

Figure 2 UNITED STATES SHIPMENTS OF MACHINE TOOLS, 1956-1980

($ MILLION, CURRENT PRICES)

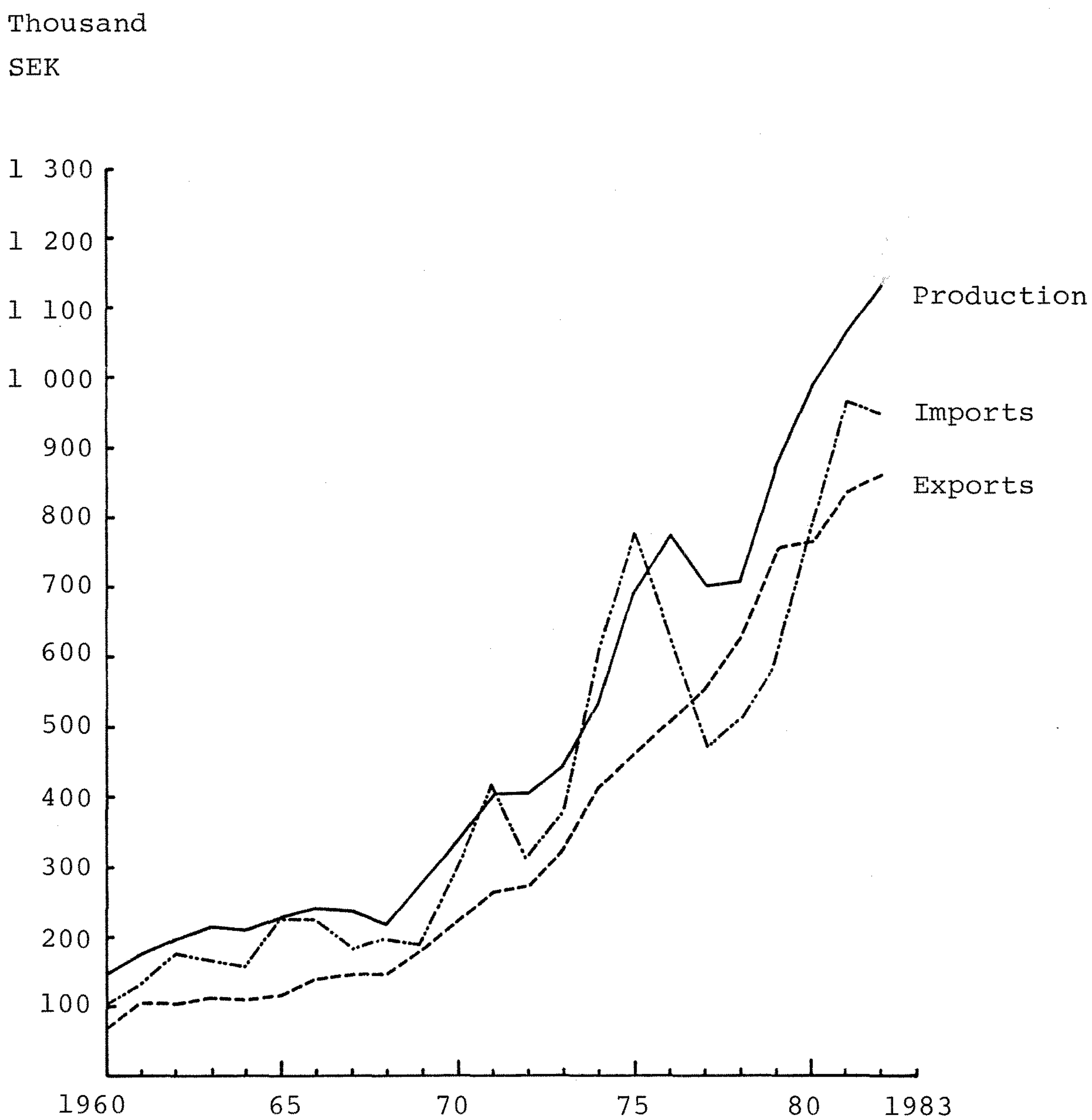


SOURCE: *Domestic and Foreign Shipments, NMTBA, Economic Handbook of the Machine Tool Industry, 1981-1982, pp. 84-87.*

Imports: 1958-1969, NMTBA, Handbook 1973-1974, p. 97. and 1969-1980, NMTBA, Handbook 1981-1982, p. 128.

Figure 3 Swedish Machine Tool Production, Exports and Imports, 1960-82

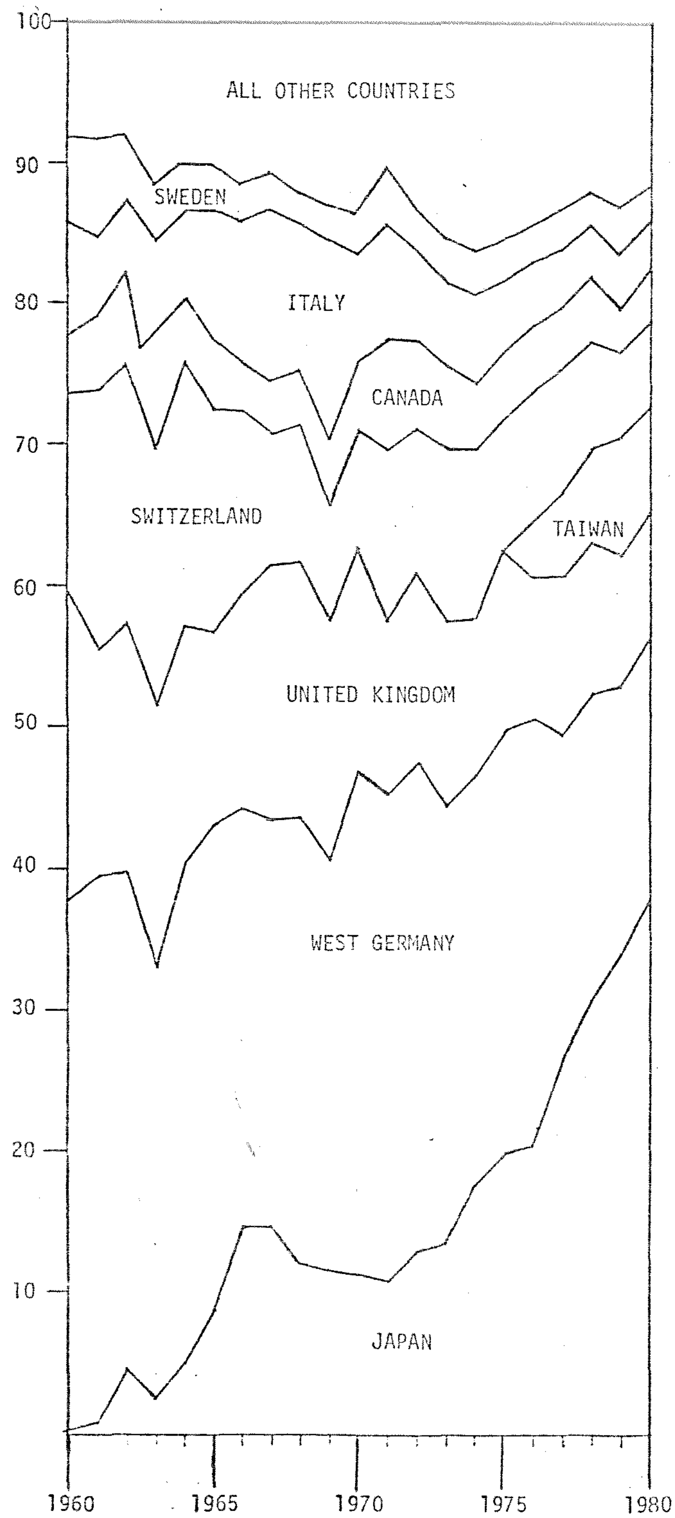
Current prices



Sources: 1960-79: SOS Industri, Yearly.

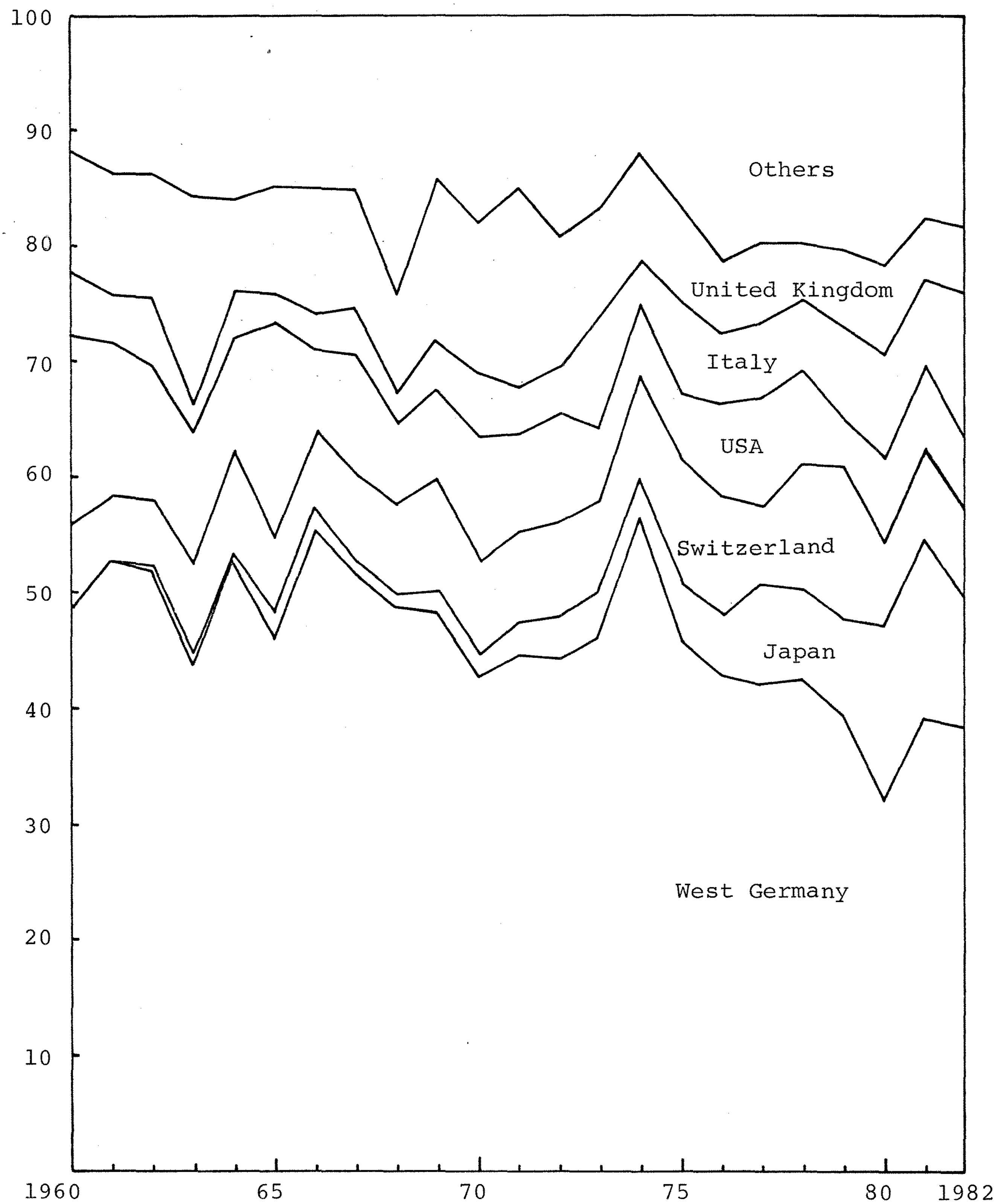
1980-82: Föreningen svenska verktygsmaskintillverkare.

Figure 4 UNITED STATES MACHINE TOOL IMPORTS, DISTRIBUTION BY COUNTRY, PERCENT, 1960 - 1980



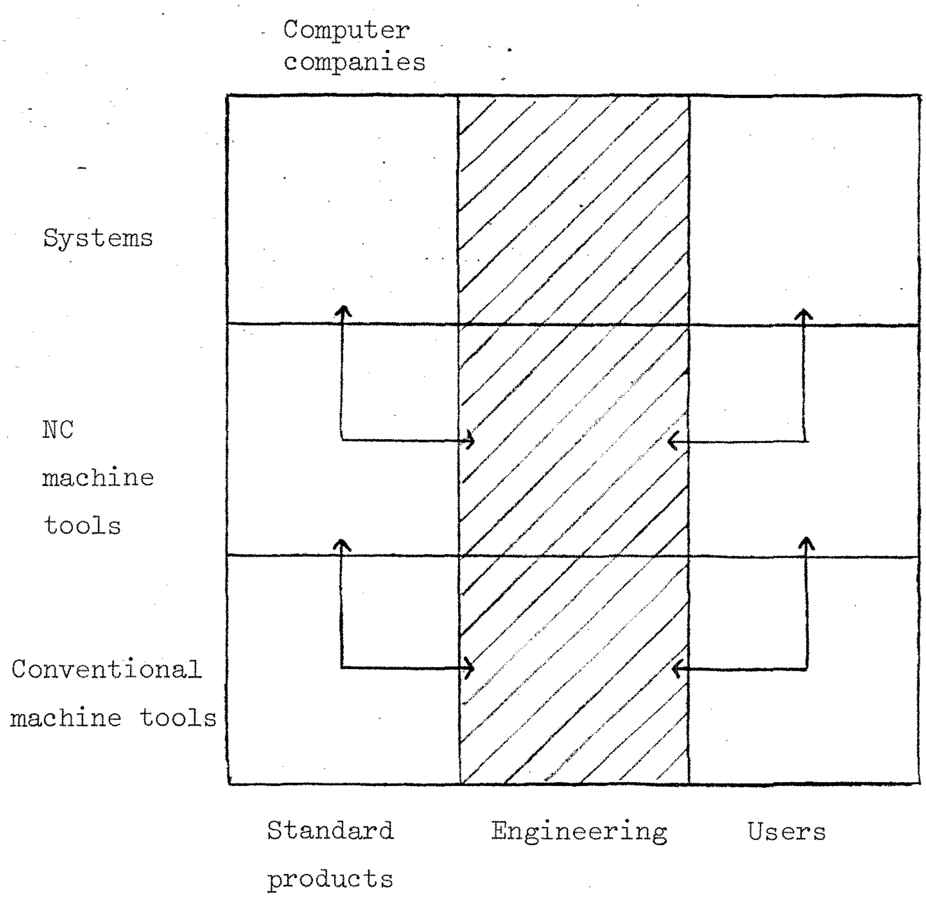
Source: NMTBA (1981-82), pp. 96 and 100.

Figure 5 Swedish Machine Tool Imports, Distribution by Country, 1960-82. Percent



Sources: SOS Industri, various issues; Föreningen svenska Verktygsmaskintillverkare

Figure 6. Product strategies of Mashine Tools Firms.



Bibliography

American Machinist, 1977, "Metalworking: Yesterday and Tomorrow", American Machinist, Vol. 121, No. 11 (100th anniversary issue).

Bright, James R., 1967, "The Development of Automation" in M. Kranzberg and C.W. Pursell, Jr. (eds.), Technology in Western Civilization, Vol. II. Oxford University Press, London.

Commission of the European Communities (CEC), 1983, "The European Machine Tool Industry. Commission Statement. Situation and Prospects." SEC (83) 151 final. Brussels, February.

Daly, Anne and Jones, Daniel T., 1980, "The Machine Tool Industry in Britain, Germany and the United States", National Institute Economic Review, Vol. 2/80, No. 92, pp. 53-63.

Klein, Burton H., 1977, Dynamic Economics. Harvard University Press, Cambridge, MA.

Kravis, I.B.; Heston, A.; and Summers, R., 1982, World Product and Income: International Comparisons of Real Gross Product. Johns Hopkins University Press, Baltimore.

Mantoux, Paul, 1961, The Industrial Revolution in the Eighteenth Century. An Outline of the Beginnings of the Modern Factory System in England, revised edition. Harper & Row Publishers, New York.

Nabseth, L. and Ray, G.F. (eds.), 1974, The Diffusion of New Industrial Processes: An International Study. Cambridge University Press, Cambridge, London.

NMTBA (National Machine Tool Builders' Association), 1981, Economic Handbook of the Machine Tool Industry, 1981-1982. NMTBA, McLean, Va.

Pursell, Jr., Carroll W., 1967, "Machines and Machine Tools, 1830-1880" in M. Kranzberg and C.W. Pursell, Jr. (eds.), Technology in Western Civilization, Vol. I. Oxford University Press, London.

Roe, J.W., 1916, English and American Tool Builders, Yale University Press, New Haven.

Rosenberg, Nathan, 1963, "Technological Change in the Machine Tool Industry 1840-1910", Journal of Economic History, Vol. XXIII, No. 4, pp. 414-443.

Secretariat of the United Nations Centre for Industrial Development, 1965, "World Machine Tool Production with Special Reference to Developing Countries".

Sonny, Jacob, 1971, "Technological Change in the U.S. Machine Tool Industry 1947-1966", unpubl. Ph.D. dissertation, New School for Social Research.

Wagoner, Harless D., 1966, The U.S. Machine Tool Industry from 1900 to 1950. The M.I.T. Press, Cambridge, MA.

Woodbury, Robert S., 1967, "Machines and Tools" in M. Kranzberg and C.W. Pursell, Jr. (eds.) Technology in Western Civilization. Oxford University Press, London.

WORKING PAPERS (Missing numbers indicate publication elsewhere)

1976

1. Corporate and Personal Taxation and the Growing Firm
by Ulf Jakobsson

7. A Micro Macro Interactive Simulation Model of the Swedish Economy.
Preliminary model specification
by Gunnar Eliasson in collaboration with Gösta Olavi

8. Estimation and Analysis with a WDI Production Function
by Göran Eriksson, Ulf Jakobsson and Leif Jansson

1977

12. The Linear Expenditure System and Demand for Housing under Rent Control
by Per Högberg and N Anders Klevmarken

14. Rates of Depreciation of Human Capital Due to Nonuse
by Siv Gustafsson

15. Pay Differentials between Government and Private Sector Employees in Sweden
by Siv Gustafsson

1979

20. A Putty-Clay Model of Demand Uncertainty and Investment
by James W. Albrecht and Albert G. Hart

1980

25. On Unexplained Price Differences
by Bo Axell

26. The West European Steel Industry - Structure and Competitiveness in Historical Perspective
by Bo Carlsson

33. The Demand for Energy in Swedish Manufacturing
by Joyce M. Dargay

34. Imperfect Information Equilibrium, Existence, Configuration and Stability
by Bo Axell

1981

35. Value Added Tax: Experience in Sweden
by Göran Normann

36. Energi, stabilitet och tillväxt i svensk ekonomi (Energy, Stability and Growth in the Swedish Economy)
by Bengt-Christer Ysander

37. Picking Winners or Bailing out Losers? A study of the Swedish state holding company and its role in the new Swedish industrial policy
by Gunnar Eliasson and Bengt-Christer Ysander

40. Wage Earners Funds and Rational Expectations
by Bo Axell

41. A Vintage Model for the Swedish Iron and Steel Industry
by Leif Jansson

43. An Econometric Model of Local Government and Budgeting
by Bengt-Christer Ysander

44. Local Authorities, Economic Stability and the Efficiency of Fiscal Policy
by Tomas Nordström and Bengt-Christer Ysander

45. Growth, Exit and Entry of Firms
by Göran Eriksson

52. Swedish Export Performance 1963-1979. A Constant Market Shares Analysis
by Eva Christina Horwitz

56. Central Control of the Local Government Sector in Sweden
by Richard Murray

58. Industrial Subsidies in Sweden: Macro-economic Effects and an International Comparison
by Bo Carlsson

59. Longitudinal Lessons from the Panel Study of Income Dynamics
by Greg J. Duncan and James N. Morgan

77. Household Market and a Nonmarket Activities (HUS) - A Pilot Study
by Anders Klevmarken

78. Arbetslöshetsersättningen i Sverige - motiv, regler och effekter
av Anders Björklund och Bertil Holmlund

1983

79. Energy Prices, Industrial Structure and Choice of Technology; An International Comparison with Special Emphasis on the Cement Industry
by Bo Carlsson

80. Energy Usage and Energy Prices in Swedish Manufacturing
by Joyce Dargay

81. ELIAS - A Model of Multisectoral Economic Growth in a Small Open Economy
by Lars Bergman

82. Oil Prices and Economic Stability - Simulation Experiments with a Macroeconomic Model
by Tomas Nordström and Bengt-Christer Ysander

83. Statlig kontroll av kommunerna
En översikt av svenska erfarenheter under efterkrigstiden
av Richard Murray och Bengt-Christer Ysander

84. Monopoly and Allocative Efficiency with Stochastic Demand
by Tomas Pousette

85. Export Performance of the Nordic Countries 1965-80
A Constant-Market-Shares Analysis
by Eva Christina Horwitz.

86. The Micro (Firm) Foundations of Industrial Policy
by Gunnar Eliasson

87. Excessive Government Spending in the U.S.: Facts and Theories
by Edward M. Gramlich.

88. Control of Local Authority Expenditure - The Use of Cash Limits
by Noel Hepworth

89. Fiscal Containment and Local Government Finance in The U.K.
by Peter Jackson

90. Fiscal Limitations: An Assessment of the U.S. Experience
by Wallace E. Oates

91. Pricing and Privatization of Public Services
by George E. Peterson

92. Export Performance of the Nordic Countries 1965-80
by Eva Christina Horwitz

93. Was Adam Smith Right, After All? Another Test of the Theory of Compensating Wage Differentials
by Greg J. Duncan and Bertil Holmlund

94. Job Mobility and Wage Growth: A Study of Selection Rules and Rewards
by Bertil Holmlund

95. Sweden's Laffer Curve: Taxation and the Unobserved Economy
by Edgar L. Feige and Robert T. McGee

96. The Machine Tool Industry - Problems and Prospects in an International Perspective
by Bo Carlsson