Cyclical behavior of productivity in the machine tool industry

Productivity growth was slow during 1958–80, partly because of the industry's tendency to retain skilled workers during cyclical downturns; computers and other electronic equipment aided production, but diffusion of such innovations has been slow

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Output per employee-hour in the machine tool industry rose at an average annual rate of 1.1 percent over the 1958–80 period—significantly below the 2.8-percent rate for manufacturing.[1] A combination of factors slowed productivity in the machine tool industry, including the tendency of machine tool firms to keep highly skilled workers on the payroll, even when output fell during cyclical slowdowns, and the slackened demand for capital goods after the mid-sixties. However, the slowdown was moderated by technological advances in the manufacture of machine tools, as well as by high rates of productivity improvement in periods of cyclical recovery.

Until 1966, productivity in the machine tool industry rose at a high annual rate, but thereafter the rate declined for several years. Its subsequent recovery remained incomplete—the high levels of the mid-sixties were not reattained. The recovery was again interrupted by a slump in 1974; it resumed in 1977, continuing to 1979, but even then productivity did not top its 1966 peak. (See table 1.) The cyclical behavior of productivity in the industry and in manufacturing is shown in the following tabulation (average annual changes in percent):

	Machine tools	*Manufacturing*
Upswings:		
1958–59	23.1	4.8
1961–66	5.6	4.4
1971–74	7.8	2.9
1976–80	2.4	0.9
Downswings:		
1959–61	-2.0	1.7
1966–71	-4.2	2.0
1974–76	5.2	3.7

Productivity in both the metal cutting and metal forming segments of the industry paralleled the cyclical patterns shown above, although amplitudes differed. Productivity improvement averaged 1.5 percent annually in metal cutting (which accounts for three-fourths of total industry employment), and 0.1 percent in metal forming. Upswings in productivity were more pronounced in metal cutting than in metal forming; downswings were more pronounced in metal forming. In metal cutting, productivity dropped in 8 of the 22 years examined (table 2); in metal forming, in 12 (table 3). The drops were only in part associated with general business cycles; they occurred in years of economic expansion as well as during contractions.

Output recovery slow in the seventies

The machine tool industry manufactures cutting tools for boring, drilling, gear cutting, grinding, and milling

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machines and lathes, as well as forming tools such as punching, shearing, bending, and forming presses. These tools are usually shipped as units, that is, as single-purpose machines, but their basic features may also be combined into "machining centers." The machine tools may be equipped with manual controls or with programmed numerical controls which require little labor by users. Machine tools are not mass produced, although they may make mass production processes possible in user industries. Rather, the parts and components of a finished machine tool are usually made in relatively small batches, and require comparatively large amounts of labor.

Output in the machine tool industry rose at an average annual rate of 1.6 percent between 1958 and 1980, compared with 3.8 percent for manufacturing. Underlying the long-term trend were cyclical swings of considerable amplitude. The metal cutting and metal forming segments of the industry traced similar cyclical patterns. (See table 4.)

The following tabulation shows the cyclical behavior of output in the machine tool industry and in manufacturing, 1958–80 (average annual changes in percent):

	Machine tools	*Manufacturing*
Upswings:		
1958–59	25.7	11.7
1961–66	14.6	8.2
1971–74	17.2	5.9
1976–80	9.1	2.9
Downswings:		
1959–61	-1.1	0.2
1966–71	-11.1	1.0
1974–76	-14.1	0.9

Recoveries in machine tool output during the seventies were less vigorous than they had been in the 1958–59 and 1961–66 upswings. Slumps were deep. Long-term factors contributing to the comparative weakening of output included the volatility in the demand for producers' durable equipment. Following 12 percent annual increases in the 1961–66 period, growth in demand for producers durable equipment contracted to 2 percent a year for 1966–71. Demand rebounded at an 11-percent annual rate in the early seventies, declined by 3 percent annually over the 1974–75 period, then recovered to a 10-percent annual growth rate in 1976–79. Even so, the long-term growth in the demand for producers' durable equipment slackened in the seventies (compared with the demand in the sixties) from an average annual growth rate of 8.1 percent in 1958–68 to 4.8 percent in 1968–79. However, the levels of the sixties were consistently exceeded subsequently—contrary to the situation in machine tool output and productivity. Thus, the relation between producers' durable output and machine tool output clearly weakened.

Table 1. Productivity and related indexes for the machine tool industry, 1958–80

[1977 = 100]

Year	Output per employee-hour	Output	Employee-hours
1958	71.5	63.0	88.1
1959	88.0	79.2	90.0
1960	84.7	82.8	97.8
1961	84.5	77.4	91.6
1962	88.5	88.0	99.4
1963	90.1	93.0	103.2
1964	99.9	112.3	112.4
1965	101.4	125.3	123.6
1966	111.7	156.1	139.8
1967	101.8	149.9	147.3
1968	97.9	137.6	140.5
1969	100.1	137.8	137.7
1970	91.7	112.0	122.1
1971	87.9	81.4	92.6
1972	98.0	91.2	93.1
1973	107.3	116.3	108.4
1974	109.4	127.4	116.5
1975	103.0	109.1	105.9
1976	98.4	93.9	95.4
1977	100.0	100.0	100.0
1978	102.6	111.8	109.0
1979	107.0	125.9	117.7
1980	106.9	129.1	120.8
	Average annual rates of change (in percent)		
1958–80	1.1	1.6	0.5
1975–80	1.3	5.4	4.0

During the seventies, a number of metalworking industries representing key markets for machine tools registered comparatively slower growth or actual declines in output. For example, production of motor vehicles after the mid-sixties rose at only about one-half the rate for 1959–66. Similarly, output growth of construction machinery contracted. Steel output, which had advanced at more than 5 percent a year until 1966, became stagnant thereafter, then fell, as did output of electric motors and generators, nonferrous metals, household appliances, and household furniture.[2]

Furthermore, expenditures for machine tools dropped as a proportion of total equipment expenditures by manufacturing firms. In the sixties, such expenditures accounted for 11 percent of the total, in the seventies, for only 9 percent. Moreover, imports increasingly displaced domestic machine tools. In the sixties and up to 1973, machine tool imports averaged well under 10 percent of total U.S. machine tool units purchased; thereafter, the volume of machine tool imports soared, and by 1978, they accounted for 21 percent of total units purchased.[3] In contrast, exports did not rise markedly relative to output—exports represented 8 percent of machine tool units purchased in the sixties and about 10 percent in the seventies.

Still another factor underlying slackened output of machine tools has been the rapid rise in their productive capacity. (This factor will be explained more fully later in this article.) A study of more than 350 companies showed that reduced machining time for numerically controlled (or programmed) machine tools ranged from 35 percent to 50 percent.[4] According to the *American Machinist's* periodic inventories of metalworking equipment, the "population" of machine tools in use did not change significantly between 1963 and 1976–78, but the output of the metalworking industries using them generally increased, indicating rising productive capabilities of the machine tools, particularly those equipped with numerical controls.[5] Some engineering authorities maintain that numerically controlled machine tools permit "drastically reduced" handling time because they eliminate the separate operations of transferring and clamping and unclamping.[6]

The relative importance of all categories of machine tools lessened during 1958–80, except lathes, drilling machines, and machining centers. (Machining centers combine the separate operations of boring, drilling, and milling units.) Most of the shift toward machining centers occurred after 1968, when the diffusion of numerical control, an essential component of machining centers, began to accelerate. In 1978, the number of machining centers shipped was half again as high as in 1968. During that decade, the number of numerically controlled metal cutting machine tools shipped more than doubled and the number of metal forming machine tools rose by 14 percent.

The diffusion of numerically controlled machine tools has remained limited, however. According to the *American Machinist's* 1976–78 inventory of metalworking equipment, only 2 percent of the machine tools in the United States were numerically controlled, and only 7 percent of machine tools 10 years old or less were numerically controlled.[7]

The output capacity of metal forming machine tools, like that of metal cutting tools, significantly increased during 1958–80, tending to retard demand and, hence, output growth. For example, the size of presses used in the automotive and appliance industries—which account for the lion's share of the demand for presses—has increased such that, in the past 15 years, it tended to be four times greater than that in the preceeding 35 years.[8] Changes of dies, which used to require 30 to 40 minutes, now take only 90 seconds—hence, long production runs are no longer needed to justify die changes.[9] Numerical controls have been applied to operations such as bending—now tube benders perform more than 30 types of bends.[10]

Table 2. Productivity and related indexes for metal cutting, 1958–80

[1977 = 100]

Year	Output per employee-hour	Output	Employee-hours
1958	67.6	58.1	85.9
1959	83.2	74.2	89.2
1960	81.5	81.0	99.4
1961	80.0	72.7	90.9
1962	83.2	83.0	99.7
1963	84.3	88.4	104.9
1964	94.9	109.2	115.1
1965	98.7	124.8	126.4
1966	107.8	154.7	143.5
1967	98.0	150.6	153.6
1968	95.7	139.8	146.1
1969	97.5	139.0	142.5
1970	89.5	107.2	119.8
1971	85.5	75.2	88.0
1972	94.8	83.9	88.5
1973	105.5	108.6	102.9
1974	108.9	122.3	112.3
1975	102.9	107.5	104.5
1976	97.3	92.5	95.1
1977	100.0	100.0	100.0
1978	103.6	113.7	109.7
1979	109.7	130.6	119.0
1980	111.2	138.3	124.4
	Average annual rates of change (in percent)		
1958-80	1.5	1.9	0.5
1975-80	2.3	7.2	4.8

Table 3. Productivity and related indexes for metal forming, 1958–80

[1977 = 100]

Year	Output per employee-hour	Output	Employee-hours
1958	83.6	78.4	93.8
1959	102.8	95.1	92.5
1960	94.5	88.9	94.1
1961	98.0	91.9	93.8
1962	105.7	104.3	98.7
1963	108.4	107.5	99.2
1964	115.5	122.2	105.8
1965	109.3	127.1	116.3
1966	123.1	160.8	130.6
1967	112.7	147.9	131.2
1968	103.9	131.7	126.8
1969	107.0	134.3	125.5
1970	98.5	126.2	128.1
1971	95.7	99.6	104.1
1972	107.5	112.1	104.3
1973	114.1	139.2	122.0
1974	111.9	142.5	127.4
1975	104.0	114.1	109.7
1976	101.7	98.1	96.5
1977	100.0	100.0	100.0
1978	99.9	107.2	107.3
1979	100.4	114.8	114.3
1980	95.2	106.1	111.5
	Average annual rates of change (in percent)		
1958-80	0.1	0.7	0.6
1975-80	-1.4	0.5	1.9

Employment concentrated in metal cutting

In 1980, employment in the machine tool industry numbered about 108,000 persons, with about one-quarter of them in metal forming establishments. Employee-hours rose quite slowly over the 1958–80 period (0.5 percent, compared with 1 percent in manufacturing) but, like productivity and output, were characterized by pronounced cyclical swings. The cyclical volatility of employee-hours in the machine tool industry, compared with manufacturing, is illustrated in the following tabulation (average annual change in percent):

	Machine tools	*Manufacturing*
Upswings:		
1958–59	2.2	6.6
1961–66	8.5	3.6
1971–74	8.8	2.9
1976–80	6.6	1.9
Downswings:		
1959–61	0.9	-1.4
1966–71	-7.3	-1.0
1974–76	9.5	-2.6

Although recoveries in employee-hours in the seventies were about as strong as in the sixties, the levels of the mid-sixties were not reached. In 1980, employee-hours were one-fifth below those of the sixties. Employment was less affected by cyclical swings and was 17 percent lower in 1980 than in 1967, the peak year of the 22-year period. The metal cutting and metal forming segments of the industry displayed comparable cyclical patterns in employee-hours. (See table 4.)

The cyclical declines in output and, hence, in employee-hours, probably aggravated the industry's perennial shortages of skilled help when business picked up again. In part, these shortages were met through overtime work. Following are relatives of overtime hours in the metal cutting and metal forming segments of the machine tool industry (overtime hours in manufacturing = 100):

Metal cutting:			
1958	60	1969	150
1959	122	1970	110
1960	144	1971	55
1961	113	1972	117
1962	143	1973	168
1963	157	1974	191
1964	181	1975	138
1965	175	1976	103
1966	203	1977	154
1967	206	1978	178
1968	131	1979	188
		1980	211
Metal forming:			
1972	134	1976	129
1973	189	1977	140
1974	206	1978	172
1975	154	1979	191
		1980	161

In only 2 years (1958 and 1971) of the review period did overtime in metal cutting fall below the manufacturing average. In all other years it was above, and often was half again to twice as high. Metal forming (for which pertinent data exist only since 1972) showed the same overtime pattern.

The number of nonproduction workers in metal cutting rose more rapidly than that of production workers, 0.9 percent per year versus 0.3 percent. There were 43 percent more nonproduction workers in 1980 than in 1958, and 38 percent more production workers, although employment of both groups was below the 1967 peak. In metal cutting, the proportion of nonproduction workers remained above 30 percent of total employment during the period, reflecting the continued importance of engineers, designers, and other leading personnel. The proportion of women also rose, from 9 to 13 percent of total employment, but was still far below the manufacturing average of 31 percent.

In metal forming, the number of production workers showed no change on average; in contrast, nonproduction workers rose 2.6 percent—from 31 percent of total employment in 1958 to 34 percent in 1980. Occupational data are not available for the machine tool industry, but are available for the metal working machinery group of industries, of which the machine tool industry accounts for about 30 percent of employment. The occupational mix in the machine tool industry is unlikely to differ very much from that in metalworking.

In 1978, metalworking machinery had an unusually high percentage of craft and kindred workers—nearly one-third of its employment, compared with just under one-fifth for manufacturing. As might be expected, the proportion of metal craftworkers and machinists considerably exceeded the manufacturing average. Operatives accounted for a smaller proportion of employment in metalworking than in manufacturing (33 percent versus 43 percent), although the proportion of semiskilled workers in metalworking was nearly three times higher (15 percent versus 6 percent). As for professional and technical workers, the employment differences were small between the metalworking and all manufacturing industries—9 percent versus 10 percent—and this was true for other white-collar categories. However, from 1970 forward, the rise in the number of professional and technical workers was almost three times greater in metalworking than in manufacturing—14 percent versus 5 percent—reflecting the growing relative importance of electronic technicians and computer and numerical control specialists and programmers.

Technology diffused gradually

A number of important innovations have been adopted in the manufacture of metal cutting and metal forming machine tools, but diffusion among machine tool producers has been slow—slower than among industries which apply the innovations in mass production. As will be documented, this slowness is related to the predominance of small firms which produce small batches of frequently complex machinery and components. The machine tool industry is labor-intensive, relative to most manufacturing industries, as indicated by the high ratio of payroll to value added. Over the 1958–77 period, this ratio averaged 58 percent for metal cut-

Table 4. Cyclical behavior of productivity in the machine tool industry and its components, 1958–80

[Average annual rates in percent]

Period	Output per employee-hour			Output			Employee hours		
	Machine tools	Metal cutting	Metal forming	Machine tools	Metal cutting	Metal forming	Machine tools	Metal cutting	Metal forming
1958-80	1.1	1.5	0.1	1.6	1.9	0.7	0.5	0.5	0.6
Upswings:									
1958-59	23.1	23.1	23.0	25.7	27.7	21.3	2.2	3.8	1.4
1961-66	5.6	6.3	3.8	14.6	16.1	10.6	8.5	9.2	6.5
1971-74	7.8	8.7	5.4	17.2	18.7	13.8	8.8	9.2	7.9
1976-80	2.4	3.7	-1.3	9.1	11.3	3.0	6.6	7.4	4.3
Downswings:									
1959-61	2.0	-1.9	2.4	1.1	-1.0	-1.7	0.9	0.9	0.7
1966-71	4.2	-4.0	4.6	11.1	-12.4	-7.8	7.3	-8.8	3.4
1974-76	5.2	5.5	4.7	14.1	13.0	-17.0	9.5	-8.0	13.0

ting establishments, and 60 percent for metal forming establishments, compared with 52 percent for nonelectrical machinery, 52 percent for transportation equipment, and 47 percent for all manufacturing. The mass production techniques made possible by machine tools generally cannot be used in building them, although significant improvements in small-batch production processes have resulted from some basic technological advances.

By far the most important development in machine tool technology has been the evolution of numerical control. In fact, numerical control has reshaped machine tool technology, and continues to transform it. Essentially, numerical control made multifunction machine tools possible (exemplified by the machining center, discussed earlier). According to *Iron Age*, numerical control tools have been decisive in achieving "the critical balance . . . . in machine construction and rigidity, horsepower, speed and feed ranges, standard tooling and management control over the machine cycle and operation."[11] Numerical control was first applied in the manufacture of machine tools in the mid-fifties, but certain innovations were required to lower its cost and, thus, spur adoption by the smaller machine tool firms. Although these innovations have occurred, their impact on productivity was retarded by the severe cyclical downturns in the industry's business in the early and middle seventies.

Numerical control is a method whereby metal cutting (and to some extent metal forming) machine tools are controlled by instructions which are programmed and then punched on a tape. Information from the tape is converted into instructions which position the tools with respect to the workpiece; no templates, drill jigs, or stops are used and manual operation is not necessary. (The operator can service more than one numerically controlled machine tool.) A feedback mechanism adjusts (or stops) the tool's movement if programmed distance does not adhere to commanded tolerance, and stops it when the process is completed.[12]

Numerical control has always required drives which would ensure that performance followed command. Hydraulic servomechanisms are still used for this purpose. In the late sixties, however, silicon-controlled rectifiers (which are solid-state devices) were introduced; these, together with improvements in the control motor, made possible much higher degrees of accuracy in machining work. Also, tool life was extended as gear transmission, hand wheels, and clutches were eliminated.[13] Perhaps most important, the substitution of transistors, and later of integrated circuits, for electric relays reduced the number of control components by up to 90 percent, and the amount of wiring by up to 80 percent.[14] These developments slashed costs, and also allowed less highly trained personnel to program the machines. Thus, improved control mechanisms gave impetus to the diffusion of numerical controls.

Numerical controls accelerated the consolidation of machine tool production—as well as the production of metalworking equipment—into machining centers. Machining centers are basically milling machines which also drill, ream, bore, tap, and so forth. In machining centers, complex shapes may be made by mounting cutting tools of varying sizes and power configurations on a single spindle. The cutting tools then are automatically changed by transfer arms, which also store the tool. These automatic tool changes take only a few seconds; formerly several minutes of an operator's time were required.[15] Machining centers also eliminate the need to design, build, and store the jigs and fixtures needed by single-purpose machines.[16]

Single-purpose machines also have been much improved by numerical controls. For example, numerically controlled boring machines have reduced downtime for loading and unloading by up to 30 percent.[17] Numerical control applied to grinding machines often halves layout time; programmable electronic wheel feed and wheel retraction have been developed which reduce labor time and enhance precision. The design of hobs for gear cutting has been subjected to computer calculation, saving cutting time.[18]

Cutting tool materials have become harder, permit-ting increased cutting speeds (albeit at the cost of requiring heavier, more powerful machines). Tungsten carbide which replaced high-speed steel in 1929 was in turn supplanted by ceramic materials and polycrystalline diamond-tipped tools. Until 1900, cutting speeds ran up to 25 feet per minute; high-speed steel tools averaged 90 feet per minute; tunsten carbide, 150 feet per minute; ceramic materials, 650 feet per minute; and polycrystalline diamond-tipped tools can cut several thousand feet per minute. Meanwhile, the older cutting materials have been improved—for example, steel tools are hardened by cobalt and continue to be widely used. Naturally, the high speeds enlarge the machine tool's output capacity.[19]

Metal cutting tools predominate over the use of metal forming tools in the manufacture of either type of machine tool. Thus, technological improvements in metal forming tools and increases in their output capacity have, of course, greatly benefited those who use the tools intensively, but have only marginally affected productivity of those who produce the tools.[20]

Computers are used in tandem with or incorporated into numerically controlled machine tools where reliability or control is crucial (as in the machining of frames for aircrafts), or where minimizing of downtime is essential. The recent trend has been toward relatively small computers interfacing with individual machines, rather than a single computer controlling a number of machines.[21] The computer has also been used in production management, as well as in the design of machine tools, significantly reducing labor requirements of engineering and drafting personnel. Conventionally, engineers and aides graphed the design for a machine tool on drawing boards, according to a customer's specifications; corrections usually required redrawing of all or most of the design to preserve proportionalities. Now, computers do the corrected redrawing, cutting the time required for such corrections. This so-called interactive graphics has permitted a 4-fold increase in the designer's productivity. Memory storage of given designs further aids productivity.[22]

Relatively old capital stock

The machine tool industry, although vital for the expansion and modernization of industrial machinery, has spent relatively little for its own plant and equipment. During the review period, the long-term growth in such spending was significantly below that for all industries. One of the results has been that the average age of equipment in the machine tool industry is well above that in all other metalworking industries.[23]

According to 1977 census data, plant and equipment expenditures per employee in metal cutting machine tools represented only 52 percent of the comparable figures for all manufacturing; for metal forming machine tools, the ratio was 40 percent. Fixed assets per worker in metal cutting and metal forming were 77 percent and 81 percent of the manufacturing average in 1976. Moreover, the long-term growth in the industry's expenditures for new plant and equipment, expressed in constant dollars, averaged 2.7 percent annually between 1958 and 1978—compared with 4.6 percent for all manufacturing industries. However, these long-term trend indicators obscure significant cyclical changes. Following are average annual rates of change in expenditures (in constant dollars) for new plant and equipment in the machine tool industry and in all industries, 1958–78:[24]

	Machine tools	*All industries*
Upswings:		
1958–59	2.3	7.3
1961–66	29.5	10.2
1971–74	28.0	7.3
1976–78	16.7	10.5
Downswings:		
1959–61	-9.5	2.4
1966–71	-18.0	1.4
1974–76	-9.6	-3.8

Cyclical patterns in the real value of the industry's capital outlays parallel those for productivity, output, and employee-hours. Even though capital outlays were strong during the upswings of the seventies, they did not reattain the levels of the sixties. In the 1976–78 upswing, the outlays were nearly one-third below those of the mid-sixties, while outlays for all industries were nearly a third higher.

The machine tool industry's low levels of expenditures for plant and equipment are reflected in the relatively high average age of its equipment. According to the *American Machinist,* 23 percent of the industry's machine tools were less than 10 years old in 1976–78, compared with 31 percent for all metalworking industries; 37 percent were 10 to 19 years old, compared with 35 percent for all metalworking and 40 percent were more than 20 years, compared with 34 percent.

The *American Machinist's* periodic inventories suggest that user industries tend to delay replacement of aging machine tools. On average, only 31 percent of machine tools in service in all metalworking industries were less than 10 years old in 1976–78, compared with 36 percent in 1968 and in 1963; 34 percent were more than 20 years old in 1976–78, compared with 23 percent in 1968 and 21 percent in 1963.[25]

The rising average age of machine tools may have been offset to some degree by the high proportion of parts and rebuilt machine tools shipped by toolmakers. Parts for metal cutting tools and rebuilt machine tools accounted for 19 percent of total shipments in 1976, compared with 14 percent in the late sixties. Parts for metal forming tools and rebuilt machinery constituted 33 percent of shipments in 1976, compared with 20 percent in the late sixties. The proportion rises in periods of slack business, but the rise may, in part, indicate intensified efforts to retrofit and upgrade aging machine tools, in lieu of purchasing new machines.

However, the high average age of equipment in the machine tool industry may have been partially offset through the replacement of worn-out parts, or by the rebuilding of machines along more up-to-date lines. Furthermore, the industry has an above-average proportion of numerically controlled machine tools—nearly 4 percent of its tools are numerically controlled, compared with 2 percent for all metalworking industries. Because numerically controlled machine tools are generally under 15 years old, they probably represent at least 6 percent of the industry equipment that has been in service less than 20 years, and surely a much larger proportion of its total output capacity.

Industry structure. The structure of the machine tool industry does not differ much from that of manufacturing as a whole. In 1972, the latest year for which data are available, the four largest of the nearly 900 companies making metal cutting machine tools accounted for 25 percent of the industry's total employment, 22 percent of its value of shipments, and 30 percent of its capital expenditures. In metal forming, concentration was slightly less. The 50 largest metal cutting companies, representing 10 percent of all establishments in the industry, accounted for three-quarters of employment, value of shipments, and capital expenditures. Trends in value added per employee by employment size class of establishment suggest that productivity has risen at a somewhat higher rate in establishments with 100 or more employees than in smaller establishments.

Accelerated demand may aid diffusion

Industry observers generally expect that demand for machine tools will remain strong. Whether this means that skilled labor shortages will persist is arguable. Skilled workers who have been laid off because of slow business in key metalworking industries such as automobiles may be available. But, because average hourly wages in these industries are often higher than those in machine tools, it may be difficult for the machine tool industry to attract such workers. Hence, incentives for technological advances in the machine tool establishments may remain fairly strong. Therefore, unless the machine tool industry also suffers from slow business, productivity should improve at somewhat higher rates than the long-term rates reported here.

Continued high levels of demand for machine tools are anticipated from automotive and aircraft manufacturers, and from manufacturers in other metalworking industries requiring more "flexible" technology for small-batch production.[26]

For the next several years, the automotive industry will be retooling for the production of smalier, more energy-efficient vehicles, at an estimated cost of $60 billion. Undoubtedly, this will strain machine tool manufacturing capacity. However, in the long run, demand for machine tools from the automotive industry is likely to slacken because of the prospective reduction in the number of automobile models.[27] Similarly, the aircraft industry may replace about one-half of its 6,000 commercial air carriers, some of which were placed in service 20 years earlier. New configurations of air frames will be needed which conform with mandated requirements to reduce noise levels and fuel consumption. Therefore, the aircraft industry will need more cost-effective machine tools.[28] Metalworking firms generally have become concerned with more efficient production of small batches of parts and components; their interest in automated batch manufacturing systems is likely to intensify. In such systems, electronically-controlled assemblages of machine tools are linked by material-handling equipment so as to convert a system of discrete parts manufacturing into one of continuous (or nearly continuous) processing.[29] Automatic-batch manufacturing systems have been increasingly used in the construction machinery industry.[30]

The building of craftworkers skills into the machine began when Eli Whitney constructed musket-making machines in the early 19th century.[31] The need "to build the skill in the machine" arose partly from the perennial shortage of craftworkers (which often resulted in unskilled workers operating complex equipment) and partly from the increased precision demanded of machine tools. Quite possibly, the diffusion of numerically controlled machine tools will accelerate the trend "to build the skill in the machine" in the eighties. As noted in the discussion on occupational patterns, this trend has affected the machine tool industry less than most other industries. This occupational pattern has been projected to persist: in 1990, the Bureau of Labor Statistics projects that 31 percent of metalworking machinery industry employees will be skilled craftworkers (only slighly below the 1980 proportion), compared with 20 percent for all manufacturing. Thus, the Bureau's projections implicitly assume that skill needs in the metalworking industry will change little; and that in the machine tool industry, it will continue to be difficult, at times even infeasible, to build the skill of craftworkers into machine tools.

Nevertheless, the diffusion of numerically controlled machine tools will probably accelerate under the spur of strong demand (which justifies the investment) and recurrent labor shortages. Also, as new generations of managers, engineers, and technicians enter the industry, numerical control and other computer-related methods will be more widely applied. The costs of these systems are likely to fall; hence, they will become more widely diffused.[32]

Although some manufacturing industries use unmanned machining systems,[33] demand is likely to be small for them. It would not be feasible financially for the machine tool industry to use such complex systems —downtime being very expensive.[34] Thus, the "unmanned factory" cannot be envisioned *for* the machine tool industry; its manufacture *by* this industry, however, can be.

It is said that automotive engine plants rely heavily on the machine tool industry for advances in their production equipment.[35] In turn, the machine tool industry increasingly relies on electronics and the computer for its technological advances. Electronics and computers will likely be dominant in machine tool production in the years ahead. □

FOOTNOTES

[1] The machine tool industry consists of machine tools, metal cutting types (SIC 3541) and machine tools, metal forming types (SIC 3542) as designated in the Office of Management and Budget's 1972 *Standard Industrial Classification Manual.*

[2] In this article, metalworking industries conform with those included in the *American Machinist* inventory of metalworking equipment and include the furniture industry (SIC 25); primary metals industry (SIC 33); fabricated metal products industry (SIC 34); nonelectrical and electrical machinery industries (SIC 35 and 36); transportation equipment industry (SIC 37); precision instrument industry (SIC 38); and miscellaneous manufactures industry (SIC 39).

According to BLS data, average annual rates of change of the output of some major metalworking or other major machine tool using industries moved as follows:

Industry and SIC number	Output *1959–66*	*1966–73*	*1973–79*
Household furniture, 251	4.8	4.5	1.9
Steel, 331	5.1	0.7	−0.8
Copper rolling and drawing, 3351	7.2	−0.1	−0.5
Aluminum rolling and drawing, 3353,4,5	9.4	6.7	2.2
Metal cans, 3411	2.8	3.9	[1]0.7
Construction machinery, 3531	5.8	3.3	1.5
Electric motors and generators, 3621	7.4	−1.2	1.4
Household appliances, 3631,2,3,9	7.6	2.8	2.7
Motor vehicles, 371	9.1	4.8	4.8

[1] 1973–78

[3] *Metalworking Machinery,* Current Industrial Reports, Series MQ 35-W (U.S. Department of Commerce, various issues).

[4] Donald N. Smith and Larry Evans, *Management Standards for Computers and Numerical Controls* (University of Michigan, 1977).

[5] "Fewer, more productive machines: The 12th American Machinist Inventory of Metalworking Equipment, 1976–78." *American Machinist,* December 1978, pp. 133–43.

[6] L. Mackay, and R. Leonard, "NC and Conventional Manufacturing Systems—A General Comparison." *Proceedings of the 18th International Machine Tool Design and Research Conference* (London, The Macmillan Press, 1978), pp. 651 ff.

[7] *American Machinist,* December 1978.

[8] "The Machine Tools That Are Building America," *Iron Age,* Aug. 8, 1976, p. 269.

[9] *Iron Age,* Aug. 8, 1976, p. 271.

[10] *Iron Age,* Aug. 8, 1976, p. 274.

[11] *Iron Age,* Aug. 8, 1976, p. 165.

[12] *McGraw-Hill Encyclopedia of Science and Technology,* vol. 13, (McGraw Hill, 1977), p. 692.

[13] *Iron Age,* Aug. 8, 1976, p. 166.

[14] *Machine Design.*

[15] *Iron Age,* Aug. 8, 1976, p. 200.

[16] *Iron Age,* Aug. 8. 1976, p. 174.

[17] *Iron Age,* Aug. 8, 1976, p. 189.

[18] *Iron Age,* Aug. 8, 1976, p. 256.

[19] L.T.C. Rolt, *A Short History of Machine Tools* (Cambridge, The M.I.T. Press, 1965), p. 223. *American Machinist,* Sept. 2, 1974.

[20] Information obtained from an industry representative.

[21] Agis Salpukas, "Computerizing machine tools," *The New York Times,* June 5, 1980, p. D2.

[22] Information obtained from industry representatives.

[23] *American Machinist,* December 1978.

[24] Expenditure data for the machine tool industry available to 1978 only. Data are from the *1980 Economic Report of the President.* Deflators are for private nonresidential fixed investment.

[25] Of the leading industrial countries, the United States has the smallest percentage of machine tools in service less than 10 years. Even so, the actual number of such tools in the United States was 803,000 in 1976–78, nearly half again as many as in Germany and Japan. (See *American Machinist,* December 1978.)

[26] *Manufacturing Technology—A Changing Challenge to Improve Productivity* (Washington, General Accounting Office, 1976).

[27] "A paucity of new models means layoffs and toolmaking plant closings, while continual changes, such as those that occurred during the mid-sixties, signal exciting mechanical challenges, full work force utilization, and extended overtime premiums . . ." H.E. Arnett and D.N. Smith, *The Tool and Die Industry, Problems and Prospects* (Ann Arbor, The University of Michigan Graduate School of Business Administration, 1975), p. 18. Estimated retooling cost from *Facts and Figures 1980,* (Detroit, Motor Vehicle Manufacturers Association 1980), p. 5.

[28] *Iron Age,* Mar. 17, 1980, p. 37.

[29] *Iron Age,* Nov. 20, 1978, p. 75 ff.

[30] John Duke, "Construction machinery industry posts slow rise in productivity," *Monthly Labor Review,* July 1980, pp. 33–36.

[31] *A Short History of Machine Tools.* See especially pp. 147–48, and 223. See also David F. Noble, "Social Choice in Machine Design: The Case of Automatically Controlled Machine Tools," in Andrew Zimbalist, ed., *Case Studies on the Labor Process* (New York, Monthly Review Press, 1979), pp. 18–50.

[32] A. Harvey Belitsky, "Metalworking Machinery," in *Technology and Labor in Five Industries* (Bureau of Labor Statistics, forthcoming).

[33] *Iron Age,* Dec. 17, 1979.

[34] *American Machinist,* December 1979, p. 82.

[35] William J. Abernathy, *The Productivity Dilemma, Roadblock to Innovation in the Automobile Industry* (Baltimore, The Johns Hopkins Press, 1978), p. 61.