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# The cutting-edge dulled: the post-Second World War decline of the United States machine tool industry

Robert Forrant*

After World War II United States preeminence in machine tool technology conveyed productivity advantages to final goods producers that enabled both machine tool builders and goods producers to prosper and provide well paying jobs to their employees. Quite soon after the war numerous technological and managerial deficiencies eroded this competitive advantage and contributed to the inability of the machine tool industry to compete successfully in the global economy. This in turn cost good producers their first access to top notch production machinery. The rusting of the machine tool industry thus contributed to the hollowing out of the country's manufacturing base and the elimination of thousands of once stable blue-collar jobs.

## Introduction

After the Second World War, US pre-eminence in machine tool technology and the productivity advantages that this accrued to manufacturers enabled its machine tool builders and goods producers to prosper, and to provide good jobs for their employees. But after out-pacing the world in the 1950s and 1960s, machine tool builders suffered through a period of sharp decline as a consequence of heightened international competition and numerous organisational and managerial deficiencies. These shortcomings include a failure to invest sufficiently in product and process developments; an inability to manage erratic business cycles; a failure to capitalise on important technology developments like computer controls; an inability to establish effective collaborations among a host of quite small firms; a disregard for customer needs; and a failure to invest in work-force development. Between 1975 and 1985 the country went from being a net exporter to being the world's largest importer of machine tools. As a consequence, goods producers lost their first access to top-notch production machinery and the significant competitive advantages over foreign producers that such machines once purveyed. The rusting of the machine tool industry thus contributed to the hollowing out of the country's

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manufacturing base and the elimination of thousands of once stable and well-paid blue-collar jobs.

The article proceeds as follows. The first section contains a brief historical overview of the machine tool industry and traces the decline of the industry since the mid-1960s. Section 2 offers an analysis of the importance of innovation for the industry through a detailed comparison of the ways in which builders in the US and Japan developed computer-controlled machine tools. The Japanese machine tool industry wrested world leadership from the US in the mid-1970s, mainly on the strength of its successful development of this technology. The divergent roles of the government, the importance of collaboration between builders and users and the role of the market are examined here. Section 3 discusses the failure of US firms to manage the extreme new-order cyclicality that plagued the industry for much of the post-war period. Section 4 offers an explanation for the overall decline of the machine tool industry and, in particular, focuses on the industry's failure to introduce manufacturing techniques to hold down production costs and speed up the product development cycle. The concluding section draws upon the evidence contained in a highly self-critical industry report to argue that the machine tool industry did not make the consistent and cumulative investments that were required to sustain itself in the face of the global competition that emerged in the 1970s and 1980s.

## 1. The US machine tool industry: early history and current trends

The machine tool industry consists of firms engaged in the production of equipment that cuts, forms, bends and shapes metal. There is a related metal-working equipment sector that is an important adjunct to the machine builders.[1] Firms are contained within two US Department of Commerce Standard Industrial Classification codes: 3541—metal-cutting machine tools; and 3542—metal-forming machine tools. Metal-cutting machines account for roughly two-thirds of the total of US-built machine tools. Metal-cutting machines include grinding machines, millers, and lathes. Forming machines include presses to stamp metal into various shapes, metal shears and saws. The easiest way to distinguish between the two categories is to remember that metal-forming machines alter the shape of metal, while the cutting machines remove metal in the form of chips (see March, 1988, Appendix A, for a useful discussion of industry technical definitions). In his study of the Burgmaster Company, Holland describes machine tools as 'the "mother" or "master" machines' that make all other machines. He adds that 'Every manufactured product is made by a machine tool or by a machine that was made by a machine tool' (Holland, 1989, p. 2).

By the middle of the nineteenth century numerous shops in the US employed skilled machinists and their apprentices and became the catalyst for the country's manufacturing pre-eminence in the late nineteenth and early twentieth centuries. In Springfield, Massachusetts, the federal armoury's nineteenth-century innovations in the use of gauges to ensure consistency in production led to dramatic improvements in the manufacture of a host of products. The diffusion of armoury best practices was fundamental to the growth of interchangability and mass production. In the 1870s, 72 firms in the country identified themselves as machine tool builders, with the majority located in New England. Several additional machine tool companies were started in Springfield, Vermont, in the 1880s

[1] Metal-working equipment firms design and build specialised dies, molds, tooling, and fixtures for machine tool builders and other manufacturers, usually on a contract basis. Important customers include the defence, aerospace, automotive, appliance, agricultural, medical, and electronics industries.

and 1890s. Lowell, Massachusetts, with its many textile mills, was home to the Lowell Machine Shop, a leading global producer of textile machinery (Gibb, 1953; Broehl, 1959; Rosenberg, 1963; Rolt, 1965; Woodbury, 1972; Cincinnati Milacron, 1984; Hounshell, 1984; Forrant, 1994).

The nation's locomotive builders, builders of mill machinery and machine tool companies symbolised America's 'rising technically driven society'. Finished goods producers, such as the Baldwin Locomotive Works, Columbia Bicycle, Singer Sewing Machine, International Harvester and Ford Motor Company, demanded continual machinery innovations from machine tool builders in order to boost their production. These producers incorporated successive machinery innovation waves on their factory floors and thus were able to produce more goods, more cheaply and with better quality than their competitors. Such first access to top-notch equipment gave firms a competitive advantage, while the builders' close working relationships with their customers prodded them to innovate and, in turn, sustain their own competitive advantages. For the Baldwin Locomotive Works and other producers, 'long-term success depended upon workers' skills, quality products, close relations with customers, and continuous technical support' (Brown, 1995, pp. 234–5). The history of the US machine tool industry in the second half of the twentieth century was marked by a turning away from these core strengths.

Through the Second World War war production stimulated the demand for improved machine tools and boosted sales. For example, in 1939 Jones and Lamson, Fellows Gear Shipper, and Bryant Chucking Grinder collectively sold 1,486 machines. By 1943 their total sales increased fivefold to 7,525. However, at the end of the Second World War orders for machine tools dissipated, caused in part by the US government sale, at 20 cents on the dollar, of 200,000 of the 500,000 machine tools it owned and had placed in important defence plants. The 'fire sale' crippled the industry, and by 1949 the total output of machine tools was just 34,500, down sharply from the 103,000 units shipped in 1945. The dollar value of these machines declined from $424 million in 1945 to $249 million in 1949 (Broehl, 1959; Wagoner, 1968, p. 319; Holland, 1989, p. 20, p. 282).[1] US builders remained dominant through the 1950s, in large part because there was little competition for sales to US producers in the expanding post-war automobile, aircraft, and other durable goods sectors. In addition, several of the largest builders received lucrative contracts from the military to design and build a variety of machine tools. But in the late 1960s this global pre-eminence began to be challenged by builders in Japan and Germany. The US industry's response to these competitive pressures was technically and organisationally bereft, and it is this internal failure that helps to explain the stunning collapse of the industry.

Since the early 1980s total US machine tool industry employment has declined almost 20%, from 70,000 in 1983 to 57,000 in 1995 (see Table 1). The 1992 Census of Manufactures determined that there were 639 machine tool plants in the US that employ 57,000 people, with the greatest concentrations of shops in the Great Lakes Region, New England and the southeastern United States. Over the same years the number of production workers dropped almost 12% from 40,000 to 35,700. For comparison purposes total employment in 1967, before the decline set in, was close to 120,000. There

[1] Just before the end of the Korean War, the US Office of Defense Mobilization put forward a plan to stabilise the machine tool industry to avoid the terrible slump that followed the Second World War. It was recommended that the government purchase $500 million worth of machine tools a year, but this did not take place. Instead, federal procurement fell steadily after the Korean War to $22 million in 1961, down from $100 million in 1954 and 1955 (Holland, 1989, p. 285).

**Table 1.** *US employment in thousands in the machine tool Industry 1975–95*

| Year | Total employment | Production workers |
|---|---|---|
| 1975 | 88·0 | 57·4 |
| 1977 | 88·5 | 57·3 |
| 1979 | 104·3 | 68·9 |
| 1981 | 104·4 | 67·3 |
| 1983 | 69·1 | 39·8 |
| 1985 | 73·0 | 45·7 |
| 1987 | 63·4 | 39·9 |
| 1989 | 67·3 | 43·6 |
| 1991 | 59·5 | 36·9 |
| 1993 | 51·4 | 31·4 |
| 1995 | 57·0 | 35·7 |

*Source:* Association for Manufacturing Technology, *The Economic Handbook of the Machine Tool Industry, 1996–97.*

are hundreds of small, family-owned firms and of the total number of firms only 88 employ more than 100 people. The typical family-owned or closely held firm employs ten to 50 people, produces just a few machines a year and has annual sales of $7–$10 million. Small firms invest very little in research and development. They have difficulty gaining any production advantages through the deployment of computer technologies and are constrained in their ability to raise capital.

The US produced $3·6 billion worth of machine tools in 1982. From 1985 to 1988 production declined steadily before it increased in the late 1980s; however, it was not until 1994 that production exceeded the 1982 figure. In 1995 $4·9 billion worth of machine tools was shipped and employment stood at 57,000. The slight increase in US sales resulted from the growth in the purchase of machine tools by US manufacturers as they emerged from the early 1990s recession. But, according to *Metalworking Insiders Report,* growth could have been substantially higher had the US industry not lost so much production capacity from previous closures and consolidations; as a consequence, the growth in domestic demand was satisfied by a steady increase in imports, mainly from Japan.

The US increase in output was part of a worldwide recovery in the machine tool industry. (For world production leaders in 1995 see Figure 1.) According to the *Metalworking Insiders Report,* the total dollar value of the output of the 37 major machine-tool-producing countries increased by 30% in 1995 over 1994. Japan, in spite of its own long recession, led the global recovery, with total shipments of $9·1 billion in 1995, up 36% over 1994.[1] A significant feature of Japan's growth, and one that demonstrates its global strength, is the fact that foreign demand has led the recovery there, unlike in the US, where exports continue to fall.

[1] In 1990 the value of machine tool orders in Japan was Y1,412,000 million. By 1993 orders dropped to Y531,800 million, 38% of the 1990 figure. Orders for 1995 were Y775,000 million, approximately half of the value of 1990 orders. Japan's increase in domestic orders comes mainly from the auto industry (*Engineering Industries of Japan,* no. 30, 1996, p. 31). Japan's output accounted for one-quarter of total world production in 1995. Machine tool output rose 43% in dollar value in Germany between 1994 and 1995, as it emerged from the European recession. Italy increased production by 31% and ranks fourth in world production and fourth in exports behind Japan, German, and the United States. Western European nations currently produce 44%, and Asian nations 38% of the world's machine tools.

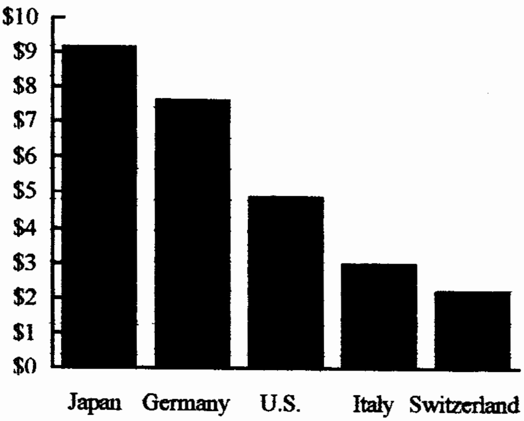


**Fig. 1.** *Top five producer nations in 1995.*

In the US, large firms, including Cincinnati Milacron, Litton Industries, Ingersoll-Rand, Monarch Machine Tool and Giddings & Lewis account for close to 70% of total industry sales. Many of these large firms achieved their current market share during merger waves in the late 1960s and the 1980s, not as a consequence of steady sales growth and the development of new products. In the 1960s the *American Machinist* cautioned that in the past mergers had created machine tool builders with complementary lines and that this had strengthened the industry. However, the latest mergers 'resulted in the acquisition of machine tool firms by large, diversified companies that have not previously been in the machine tool business' (Holland, 1989, p. 84). When sales were high the new owners invested their profits in other businesses, while during downturns they failed to make the necessary investments in training and technology that were required to keep the industry competitive; instead, the assets of the machine tool firms were sold off, thus further debilitating the industry.[1]

There are two principle ways for the machine tool industry to increase its sales: either there is an industrial expansion that requires customers to add equipment to meet this new demand; or customers decide to replace their old and/or obsolete machinery. In the US, the strongest post-Second World War expansions in the industry were related to the military demands of the Korean and Vietnam wars. At other times replacement demand was modest as goods producers tended to keep machine tools in production for 15 to 25-year periods (Holland, 1989, p. 283). The industry depended, as well, on the vicissitudes of demand from the automobile industry. And, like defence, automobile machines had little direct application for anything other than the automobile industry (Wagoner, 1968, pp. 92–3; Noble, 1986). As a consequence of this focus on defence and automobiles, there was little organisational transfer of engineering and production knowledge among tool builders to the development of machines for their other customer markets.

This would not have been a significant problem had three things remained constant: first, the defence and automobile industries, in spite of their ups-and-downs, continued to grow; second, there was little or no international competition in the production of more general purpose machine tools; and third, the pace of machine tool innovation remained

[1] For example, Bendix acquired the Warner and Swasey Company in 1983 and almost immediately transferred most of Warner and Swasey's production to the Japanese machine tool company Murata, thus hollowing out this once venerable US company (NRC, 1983, p. 44).

**Table 2.** *Ten largest machine tool builders in 1994 by sales in millions of $US*

| Company | Country | Sales |
|---|---|---|
| Amada | Japan | 845·6 |
| Yamazaki Mazak | Japan | 732·1 |
| FANUC | Japan | 730·0 |
| Fuji Machine | Japan | 617·2 |
| Giddings & Lewis | US | 557·3 |
| Western Atlas | US | 502·0 |
| Okuma Machinery Works | Japan | 471·1 |
| Mori Seki | Japan | 440·5 |
| Schuler Group | Germany | 417·2 |
| Thyssen Maschinenbau | Germany | 416·8 |

slow. However, none of this held true by the mid-1960s.[1] Up until then, the US was the world's largest producer of machine tools, with nearly 30% of global shipments. But by the early 1970s Japanese firms were more adept at fusing computer technologies with machine tools in order to design and build affordable computer-controlled machines for the many small and medium-size companies in Japan and the US

By 1994, based on total sales, 56 of the top 200 machine tool firms in the world were Italian, 49 were German, 44 were Japanese, while just 25 were in the US (See Table 2 for the ten largest builders by sales volume.) By 1995, the US imported nearly six time more machine tools by dollar value than did Japan (DiFilippo, 1986, p. 7; Critical Technologies Institute [CTI], 1994, vol. 1, pp. 11–12; Association for Manufacturing Technology, 1995; Tsuji, Ishikawa and Ishikawa, 1996, pp. 31, 35). Japanese firms dominate in the sale of computer numerical control machining centres, and Japan-based FANUC is easily the world's largest producer of computer control systems, the brains of state-of-the-art machine tools. Three other East Asian countries, Taiwan, China and Korea, rank sixth, seventh and eighth, respectively, in the global production of machine tools. Under the weight of heightened global competition, a lack of purchases by the US 'Big Three' automobile assemblers, and the overall decline in several categories of domestic manufacturing, 600 of the 900 US machine tool builders with fewer than 20 employees permanently closed their doors between 1982 and 1987.

## 2. Machine tool production and the innovation dynamic

The US machine tool industry's principle customers in aerospace, automobiles and non-electrical machinery had growth rates of only about 2% between 1979 and 1986 and, as a consequence, domestic machine tool consumption declined. However, these low customer-growth rates do not fully explain the industry's deep and lasting contraction. For while the consumption of machine tools declined 0·6% per year from 1977 to 1986, their production declined by ten times that rate. The contraction is accounted for by the rise in

[1] The industry spent approximately 2% of sales on research and development. Many firms were selling machines with basic designs which dated back to the Second World War (Young and Dunlop, 1992, p. 80). Industry output was predicated on long product life cycles.

the importation of machine tools from Japan and the decline in exports (National Machine Tool Builders Association [NMTBA], 1987; Corcoran, 1990). An understanding of the builder–user innovation process is vital to an explanation of how this came about.

In the first half of the twentieth century the output demands on various mass-production industries spurred innovation in the machine shop sector, and thus contributed to the success of those builders and manufacturers who worked in close, consultative relationships. For instance, the demands posed by early twentieth-century automobile companies for machinery that could produce greater output resulted in the development of several new machines, including multiple spindle drill presses to work cylinder blocks and heads, a machine to grind the cylinders themselves, a lathe to turn camshafts and a vertical turret lathe to turn flywheels (Broehl, 1959; Rosenberg, 1963; Carlsson and Taymaz, 1993). This interaction between machine tool builders and their customers is critical. Leading users have the ability to 'articulate the technical problem to be solved', and without such users there is 'no basis for a strong domestic machine tool industry' (Carlsson and Jacobsson, 1991, p. 5). A basic machine tool industry must be present for the innovation process to work; then, once sufficient demand for a technology occurs, a specialised group of builders will emerge (Rosenberg, 1963; Hounshell, 1984).

An iterative, cumulative process—the ratcheting upward of machine tool performance followed by the dispersal of the new equipment on factory floors—was a cornerstone of US manufacturing success dating back to the Springfield Armoury and the spread of various gauging techniques to ensure uniform parts production (Best and Forrant, 1996). This was a symbiotic relationship, for the continuous sales gains that manufacturers made required them to push machine tool builders harder to innovate and produce new and better technologies so that they could maintain their market advantage. According to Hounshell (Hounshell, 1984), as each production problem was solved by machine tool companies and goods producers 'new knowledge went back into the machine tool firms, which then could be used to solve production problems in other industries'. Cincinnati Milacron's centennial history contains numerous examples of how this dynamic worked with the automobile industry, particularly in the development of grinding machinery (Cincinnati Milacron, 1984). Carlsson characterises the industry, in the more recent period, as a 'node' for 'supplying hardware and software to all metal-working industries, thus playing a crucial role in determining the performance of large sectors of manufacturing in terms of productivity and international competitiveness' (Carlsson, 1989, p. 246).

However, once a downward trajectory marks one or the other of the partners in the machine tool design, building and utilisation process, each partner will suffer the consequences. A weakened machine tool industry in country *A*, impinges upon the ability of that country's goods producers to compete with those firms from country *B* that have first access to state-of-the-art machine tools from country *B*'s machine tool companies. In turn, the manufacturers in country *A*, weakened by their international competitors, spend less on new machine tools, and do very little to push their machine tool builders towards greater innovation and design improvements. A downward cycle is set in motion that is extremely difficult to abate. It was this negative dynamic that contributed to the overall decline of US machine tool firms and goods producers, while the innovation dynamic present in Japan, as well as Germany, fostered by industry-led research activities, government-supported policies and close collaboration with customers, offered a powerful antidote to such stagnation (Ruth, 1996).

*The innovation process in the United States and Japan: the case of computer controls*

The US and Japan took quite different paths as they developed computer controls for machine tools. It is not an exaggeration to state that the epicentre of Japan's late twentieth-century manufacturing advantage is its successful development of computer controls for a wide array of machine tools suitable across numerous industries. It is also not an exaggeration to argue that the flawed efforts of US machine tool builders, linked directly to large-scale research projects funded by the Defense Department and prime defence contractors, has greatly contributed to the weakened overall state of the US industry and, by extension, manufacturers who relied on gaining first access to first-class production equipment. In the post-war period in the US, the would-be partners in the manufacturing innovation process—machine tool builders, manufacturers, universities, the government—disregarded their own history. Wagoner determined that progress in machine tool design from 1900 to 1950 was 'often stimulated by developments in other industries' and that major changes 'resulted from a combination of applications engineering and skilled workmanship to solve practical metalworking problems...' (Wagoner, 1968, p. 327). The Rand study noted that 'It is much easier to develop tools tailored to the needs of a particular manufacturer if the machine tool maker is nearby and has developed a long-term relationship with the user, particularly as this process will often involve sharing proprietary information' (CTI, 1994, vol. 1, p. 38). However, US manufacturers were not purchasing new machine tools, thus slowing innovation demand-pull. In 1973, 33% of machine tools in use in the US were less than ten years old, as compared to 60% in Japan. By 1978, 40% of US machines were over 20 years old, while in Japan the figure was just 18%. This not only hurt machine tool sales, but it hindered manufacturing productivity and competitiveness, since it meant that US manufacturers were competing with Japanese producers operating with newer technologies. Even the average age of the machine tools utilised by builders increased as less attention was paid to the shop-floor innovation process and owners became preoccupied with business problems, cost accounting and profit ratios (March, 1988, pp. 16–18; National Research Council [NRC], 1983, p. 2).

In the late 1950s US industry leaders did take some notice of Japanese machine tool builders, but dismissed them as unworthy rivals for worldwide sales. For example, the *American Machinist* noted that Japanese firms were 'moving into the international arena big time', but pejoratively added that their machines were simple, and only appealed to 'Southeast Asia and other industrially backward nations'. While the *American Machinist* did point out that Japan's Ministry of International Trade and Industry was supporting the development of specialised machine tools and a computer numerically controlled jig borer, suitable for use in small machine shops, it failed to grasp the significance of its own report, and all the while myopic US builders lost sight of Japan's efforts to develop a broad range of exportable, stand-alone and low-cost machine tools, appropriate for the hundreds of small shops in Japan and the US (*American Machinist*, 1 June 1959). After the Second World War Japan did not aim for high-performance niches as it produced machine tools; instead, it designed and built consistent, reliable, low-cost, standard products that many firms could use (March, 1988, p. 5). As a consequence of these internal developments, Japan's reliance on imported machines dropped sharply. Once tool builders in Japan, with a good deal of government support and the backing of a vigorous trade associations, successfully directed their attention to the development of appropriate computer controls for these basic machine tools, global sales expanded, particularly to the US where manufacturers eagerly purchased Japanese machine tools. By the 1980s the US had become the leading global importer of machine tools, with a trade deficit of \$1·7 billion, which grew to \$2·2 billion by 1995. Of these imports, 41% came from Japan in the form of computer numerically controlled machining centres and lathes.[1]

Numerical Control (NC) technology had its genesis in research conducted at the Servo-mechanisms Laboratory at the Massachusetts Institute of Technology (MIT) in the early 1950s. MIT's initial involvement came through a subcontract it received from machine tool builder John Parsons. Parsons needed help to develop a set of controls for a complex machine tool he was building for the air force, to perform consistent and automatic contour cutting on aircraft wings. Eventually, MIT received a direct contract from the air force and squeezed Parsons entirely out of the effort.[2] In 1952, MIT demonstrated its control system on a Cincinnati vertical milling machine. With air force funding, MIT, Cincinnati, Bendix, (Kearney & Trecker) (Giddings & Lewis) and several aircraft builders individually set out to build machines (Ashburn, 1990, pp. 46–7).

To confound the MIT project further, five companies, Bendix Aviation, Cincinnati Milling, General Electric, Giddings & Lewis and Electronic Control Systems separately set out to build distinct control systems for the machines (Noble, 1986; Ashburn, 1990, p. 47). The NC divisions of these companies eventually sold their controllers on the market, but with only limited success, partially because each firm's system remained proprietary. By 1970, ten machine tool builders had developed their own controls and each one 'designed a control unit to provide the optimal functions for its own range of machine tools, and competing firms control units were incompatible' (Collis, 1988B, p. 11). Thus, equipment integration and substitution was almost impossible. In summary, the development of a complex technology was made more complicated because first, so many firms were involved in a thoroughly uncoordinated way; second, the all-important controls were developed without any specific established standards; and third, the machine tools and controls were designed and built to engage in the exotic and difficult task of machining the skins of aircraft wings. Ashburn concluded that the MIT programme created the 'the initial impression that NC was something that could be used effectively only by aircraft firms working with a government subsidy' (March, 1988, p. 23; Ashburn, 1990, pp. 47–8).

In his history of the Burgmaster Company, Holland states that the air force directed the attention of the machine tool industry to NC through its investment of an estimated \$62 million in research and development and machine tool purchases. However, the air force role was a 'mixed blessing'. While the MIT-researched air force machines worked well under laboratory conditions, when the machine tools were placed on actual shop floors

[1] In 1995, Japan, Germany, Switzerland, Italy, Taiwan and Spain had a positive trade balance in machine tools, while Korea, China, and the US ran trade deficits. The US deficit was the largest in the world at over two billion dollars, while Japan's surplus was the largest in the world at slightly over five-and-a-half billion dollars. US imports of machine tools were \$167·1 million in 1973, \$318·3 million in 1976, and slightly over one billion dollars in 1979. As a percentage of total purchase of machine tools, imports climbed from 9·7% to 22·2% during these same years (National Machine Tool Builders Association, *Economic Handbook*, 1987.

[2] MIT's engineers attempted to develop a universal system capable of commanding a machine tool to cut any mathematically definable contour. This required the development of what MIT engineers called 'continuous path NC'. A more simple system, known as point-to-point, was used by companies like Burgmaster, to instruct machine tools to perform simple drilling and milling procedures (Holland, 1989, p. 284; Noble, 1986).

and were exposed to vibrations, electrical interference, dirt, and operators who were never properly trained to handle the tape controls, the machines failed. And because the firms that built the air force prototypes were so heavily subsidised, they paid scant attention to cost controls and thus produced products that were in Holland's words 'far more sophisticated than anything a civilian manufacturer might need, or be willing to pay for' (Holland, 1989, pp. 34–5). In fact, the resultant machines in the air force project were so 'complex, expensive, and cantankerous' that no aircraft builders were willing to purchase them, and the air force itself subsidised commercial development by purchasing 100 five-axis continuous path profile milling machines, 25 each from Cincinnati Milling, Giddings & Lewis, Kearney & Trecker and Morey Machine.

Compare this history to what transpired in Japan where, early on in the promotion of NC technology, controls built by Fujitsu Automatic Numerical Controls (FANUC) became the recognised standard. The first public hint at what was happening in Japan came through a machine tool show in Osaka, Japan in 1970. At the show, a system of 28 machine tools was being operated with controls built by FANUC.[1] Several of the machines were producing the parts that were used to assemble the pulse motors in FANUC's controls. In other words, the machines were producing parts for themselves (Ashburn, 1990, p. 52). In a 1974 article in *World Manufacturing*, Tokyo Bureau chief Michael Mealey reported that the entire production process at FANUC's Hino factory was under computer control. 'Computers keep track of orders, parts inventory, parts purchase, production schedules, and parts testing', he wrote. Computers also controlled such complex activities as the assembly of NC parts, the mounting location of electronic components, and final assembly of NC systems. Mealey reported that FANUC was opening a service centre in the US to boost exports (Mealey, 1974, pp. 31–4).

How was this possible, when US firms were having such great difficulty developing an affordable controller? The government of Japan, through the Ministry of International Trade and Industry (MITI), played a pivotal role as part of an overall strategy to rebuild the country's manufacturing base, as did the Japan Machine Tool Builders' Association (JMTBA). The JMTBA was formed in 1952 by 40 of the country's largest builders to act as their voice with the government and to facilitate the exchange of technical information among member firms (Holland, 1989, p. 111; Tsuji, Ishikawa and Ishikawa, 1996). In the 1950s the JMTBA and the government often clashed over policies related to the industry. For example, in the 1950s builders wanted their markets protected, while MITI wanted to boost the output of all Japanese manufacturers. In the end, rather than apply high tariffs to keep foreign machine tools out of the country, MITI instituted financial incentives for its manufacturers to purchase domestically-built equipment.[2]

Two national laws, the *Gaishi-ho* (Foreign Capital Law, 1950), and the *Kikaikogyo Rinji Sochio-ho* (Temporary Measures for the Development of the Machinery Industry Law, 1956) helped machine tool builders to gain access to foreign technology and much needed

[1] FANUC started as a division of electronics giant Fujitsu and competed with several US firms, including General Electric, Bendix, Sperry UMAC, and Actron, in the development of machine tool controls. It was a 1972 spin-off from Fujitsu. In the early 1970s, Bendix still owned all the basic NC patents and firms licensed the technology from Bendix at a cost of $500,000–$1,000,000 per licence (Critical Technologies Institute, 1994, vol. 2, p. 108).

[2] Tsuji makes the point that Japan's technology acquisition strategy is in marked contrast to the one deployed by many other East Asian countries in the 1980s. Japan licensed technology while other nations employed a strategy based on direct foreign investment in their countries (Tsuji, Ishikawa and Ishikawa, 1996, p. 5).

capital. The Foreign Capital Law encouraged and regulated the introduction of foreign technology to help the industry 'catch back up' after the destruction caused by the Second World War. Licensing agreements with foreign machine tool companies were brokered by MITI, while direct foreign investment in Japanese machine tool firms was discouraged. Twenty-nine technology licensing agreements were established with foreign builders between 1961 and 1964, as firms sought to learn about conventional machine tool developments in order to 'join the race for innovation' in more advanced technologies. Japanese firms that benefited from the agreements include Mitsubishi Heavy Industries, the Toshiba Machine Company and Toyoda Machine Works. The US firms involved include Burgmaster, Van Norman, Kearney & Trecker, Warner Swasey and Bryant. Between 1952 and 1981, when the law was repealed, 161 foreign technology licensing agreements were made. Joint production ventures with US firms included: Koyo and Van Norman to build centreless grinders; Toshiba Machine and Kearney & Trecker to build transfer machines; Sansei and Bryant to build centreless grinders; and Murata and Warner Swasy to build a variety of machines. Countries with the most agreements were the US with 67, West Germany with 33, France with 32 and Switzerland with 18 (Chokki, 1986, pp. 131–2, 134; Tsuji, Ishikawa and Ishikawa, 1996, p. 22).

For a time these licensing agreements provided an opportunity for US firms to gain entry to the Japanese market. Burgmaster signed one such agreement in 1962 with Chukyo Denki, a Nagoya-based machine tool firm. In the past Burgmaster had fought with Chukyo in patent court, arguing that Chukyo was copying some of its machine designs. The licensing agreement provided the Japanese company with the rights to build and sell Burgmaster-designed machines in Japan and other Asian countries. In return, Burgmaster received a one-time payment for the engineering designs and annual royalties on sales. Over time these agreements cut heavily into US sales in Japan; machine tool exports to Japan fell 50% in 1963 and an additional 50% in 1965. But, in the midst of large order-backlogs caused by the demands of the Vietnam war, American builders failed to take note of this drop off. Equally ominous, and unnoticed, Japan's machine tool exports to the US rose from \$2·4 million in 1964 to \$26·2 million in 1967 (Holland, 1989, pp. 48, 122, 124). In his analysis of the licensing law, Chokki downplays its importance, arguing that the resultant production and sales capacity was minimal. However, it appears that sales were of secondary importance compared to the rapid gain in technical knowledge from the then world leaders in the industry. The hunt for, and widespread diffusion of, technical knowledge remained incessant in Japan. For example, in 1960, Hitachi Seiki started a technical institute and Toyoda Machine Works established a research institute as a subsidiary company. Such expenditures on research were uncommon among US firms.

Under the Temporary Measures for the Development of the Machinery Industry Law, 21 industries were selected by MITI for modernisation assistance. MITI extended long-term, low-cost government loans through the Japan Development Bank for firms in the targeted industries to invest in new equipment. The law encouraged machine tools firms to specialise, and it helped machine tool builders to standardise their parts across a number of machines to reduce their production costs. As a result, firms specialised in markets in which they could 'seize a significant share and achieve economies of scale in production' (CTI, 1994, vol. 2, p. 3).

MITI and the JMTBA established a government approval process for product development that helped regulate research expenditures among firms, and attempted to guarantee that those firms that did invest in product development had a protected domestic market (Tsuji, Ishikawa and Ishikawa, 1996, p. 9).[1] An important adjunct to the government role was the ability of machine tool builders to work together and share knowledge. While MITI played a role in the rapid turnaround of the industry, the firms themselves embarked on their own aggressive modernisation campaigns, using MITI programmes as their launching pad (Friedman, 1988). According to Yoshimi Ito, of the Tokyo Institute of Technology, these industry research and development efforts were supported by a well-configured human network 'organised on the basis of "Alma Mater" and also of the close society called "Machine Tool Engineer's Family".' As Ito describes it, the Japanese machine tool society is small, and has 'an implicit system to transfer the grass-root like knowledge, information, and technology from the senior to the junior engineers as like the "Inheritance from Father to Son".' It was the ability to pass on organisational learning within and across firms that was 'one of the basic prerequisites' for the success of Japanese machine tool firms in the world market (Ito, 1996, p. 108).[2]

In summary, during the period of development of computer controls, US machine tool builders focused most of their research and development effort on solving Pentagon-related problems, because that is where the money came from. The Pentagon heavily influenced what was designed and built through the technical specifications it required of machine tools. In one case the government ordered eleven 4-spindle, 5-axis machines to be built at a cost of $1 million each. There was already available a 4-axis machine for $150,000 that could do much of the work required. The government's insistence on such customised machines influenced the direction that many US machine tool firms took, and raised design and building costs without significantly affecting performance. The NRC determined that such customised design requests often diverted scarce engineering and management time to the construction of machine tools that 'will not be useful to other machine tool customers' (NRC, 1983, p. 67). In sharp contrast to this approach, it was simplification, standardisation, miniaturisation, and systematisation that drove companies like FANUC, and Mori Seki, as well as their customers in the automobile, semiconductor fabrication, and consumer electronics sectors to participate together in the development of highly successful new manufacturing knowledge. It was the expanded market share provided by the successful development of computer-based machine tool technologies that allowed Japan's machine tool firms to make continual investments in automated equipment and assembly systems to increase their own productivity and, in turn, build lower-cost machines.

In addition, access to world-class machine tools gave production advantages to the Japanese automobile and consumer electronics producers who were able to deploy the equipment in advance of their international competitors, in much the same way that US producers had achieved production advantages in the first half of the century. According to the director of a 1986 General Motors study on machine tools, 'If you buy the very best from Japan, it has already been in Toyota Motors for two years, and if you buy from West Germany, it has already been with BMW for a year-and-a-half' (March, 1988, p. 3). Builders also gained advantages from their relationships in *keiretsu*. Machine tool builders

[1] For detailed accounts of the government's role in machine tool development see Friedman (1988) and Vogel (1985). Friedman and Vogel differ in their analysis of the impact of these laws. Firms often resisted government pressure to move out of product markets and also entered markets set aside for other firms. But the government did help to bring coherence to the industry and boosted industry efforts to develop NC technology.

[2] By the end of the 1950s the Japanese machine tool industry had been reconstituted. In 1960 annual production was $150 million, up from $10 million just five years previously. MITI's original plan was for the industry to spend about $167 million on new capital investments; by 1960 the figure was $492 million.

**Table 3.** *Numerically controlled metal-cutting machine tools produced and consumed in the United States in selected years*

| | Domestic Production | Export | Import | Consumption |
|---|---|---|---|---|
| 1980 | 8,889 | 959 | 4,524 | 12,454 |
| 1982 | 5,116 | 659 | 5,549 | 10,006 |
| 1984 | 5,124 | 479 | 7,655 | 12,300 |
| 1986 | 4,633 | 606 | 12,146 | 16,173 |

*Source:* Ashburn, 1990, p. 53

were often members of a business association that contained numerous firms with a financial stake in the machine tool builder. This provided tool builders with a ready market and, equally important, access to innovation ideas. Toyoda Machine Works, for example, began to manufacture large numbers of machine tools for Toyota Motors which owned 24.9% of Toyoda Machine Works stock, while Toshiba Machine built machines for Toshiba Corporation, owner of 50.1% of Toshiba Machine stock. Along with these customer links, several machine tool builders gained access to financing from the major bank in the *keiretsu* to which they belonged (Chokki, 1986, p. 138; Sarathy, 1989).

How rapid was the growth in demand for NC machine tools? In 1979 computer-controlled machine tools comprised 9% of unit output in Japan and 2% in the US. By 1991 these figures were 42% and 7%, respectively (Friedman, 1988, p. 124; March, 1988; CTI, 1994, vol. 2, p. 13). With small and medium-sized CNC lathes and machining centres representing about 30% of the worldwide demand for machine tools in the early 1980s, Japan's first-mover domestic status in the industry helped firms there to dominate the global export market.[1] On the other hand, the loss of major portions of its own sizeable domestic market seriously damaged the financial position of US firms. (For the size of the US domestic market see Table 3.)

Ashburn provides detailed information on the growth of the NC market. From 1953 to 1958 less than 200 machines were installed in the US, but thereafter sales increased. Three times more units were sold in the US in 1959 and 1960 than between 1943 and 1958. By 1967 NC machines comprised 21% of the metal-cutting machine tools shipped in the US, Still not many units, but a market with growth potential. US firms never captured even the domestic growth potential, and soon lost their own home market to Japanese imports. For example, in 1984 NC turning machines and machining centres comprised 25% of the value of machine tools built in the US and 42% of the value of imported machine tools. Using Manufacturing Census data and reports from the NMTBA, Ashburn determined that in the mid-1980s, 'all types of NC were accounting for almost half the US consumption of machine tools, and more than 60% of the NC machines were being imported' (Ashburn, 1990, p. 51). In 1991 the US provided less than 40% of its own domestic market in horizontal NC lathes and forging machines. The total dollar value of US CNC production in 1991 was lower than it was in 1982, in spite of the tremendous worldwide growth in demand for the technology, and an increase in US demand from $1·25 billion in 1983 to $2·2 billion in 1991 (CTI, 1994, vol. 1, p. 15; vol. 2, pp. 5, 104).

[1] CNC exports came to dominate machine tool exports from Japan. In 1975 the ratio of their exports to all machine tool exports from Japan was 13.1; by 1983 it was 65.5 (Chokki, 1986, p. 148).

## 3. The failure to manage industry cyclicality

The more streamlined production process utilised in Japan made it possible to turn orders around promptly to satisfy customer demands and ensure low unit costs. This resulted in the steady growth of Japanese machine tool sales worldwide. US builders could have benefited from these techniques in the face of the extreme order cyclicality of the US market, tied as it was to the vagaries of the automobile and defence sectors for its largest orders (DiFilippo, 1986, pp. 89–93; Corcoran, 1990, p. 230). However, they did not, and the majority of builders strove to ride out order cycles, as they had done before the competitive challenge from Japan existed. (See Figure 2 for the percentage change in new orders from the late 1950s to the early 1980s.)

According to the National Academy of Engineering 'perhaps the most important trait associated with the machine tool industry is the extreme cyclicality of its income, profits, and cash flow' (NRC, 1983, p. 10). For example, in 1956 there were order decreases of almost 50% compared to 1955, followed by increases of 75% in 1958; and order increases of almost 90% between 1970 and 1972, followed by a sharp drop to pre-1970 levels between 1973 and 1975. Without serious global competition, US firms 'managed away' these dramatic order swings at the expense of their customers by maintaining extremely large backlogs of work; in some instances, shipments lagged two to three years behind the actual customer orders. Holland found that between 1964 and 1965, when Burgmaster introduced a series of new NC machines, orders increased to $16 million from $8·4 million, while shipments increased just 18%. (Figure 3 traces new orders and order backlogs between 1960 and 1994.) By January 1966 the order backlog for the NC equipment reached $30 million, while Burgmaster shipped approximately $900,000 worth of machines each month. Customers were forced to wait up to two years to take delivery on the machines they needed to boost their own output (Holland, 1989).[1] This strategy did not endear builders to their customers, and at the same time it left builders vulnerable to any competitor capable of producing low-cost, high-quality equipment that could be delivered on time (March, 1988, p. 12, pp. 106–107).

In fact, the surge in the importation of machine tools from Japan closely mirrored the mid-1970s US industry build-up of unfilled orders. The rapid acceleration of exports from Japan to the US made it possible for Japan's machine tool firms to invest in automated equipment and assembly systems to further increase their productivity and lower their production costs. Three important shop-floor changes were introduced. First, machine tools were redesigned to increase the number of common parts across the entire range of machines that a firm built. More common parts meant longer production runs of the parts. Second, while US firms began to work to drive down costly machine set-up times, Japanese firms were well on their way to eliminating entirely many set-ups through machine redesigns and the deployment of worker continuous-improvement teams. Third, since the machine tools were designed with fewer total parts, this simplified assembly and therefore decreased assembly time (Japan Society, 1994). Taken together, these engineering and design changes lowered production costs and reduced the time it took to fulfil a machine tool order for a customer.[2]

[1] Burgmaster tried to manage the backlog by using several outside machine shops. In some cases less than 10% of the machined parts that went into one of their machine tools was actually completed on site (Holland, 1989, p. 70).

[2] The 1981 study tour of US builders noted that 'machine assembly was accomplished by teams' and that, while assembly methods are not substantially different in the two countries, 'their machines have been designed for easy assembly' (NMTBA, p. 22). Study mission participants included: Joseph Clancy, President

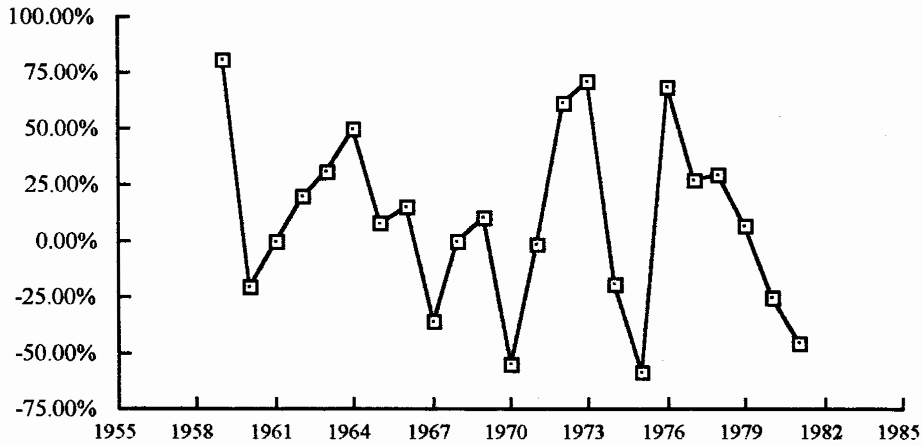


**Fig. 2.** *Percentage change in yearly new orders in the US machine tool industry 1958–1982.*
*Sources:* National Machine Tool Builders, *Economic Handbook 1984–1985.*
Data table in DiFilippo, 1986, p. 90.

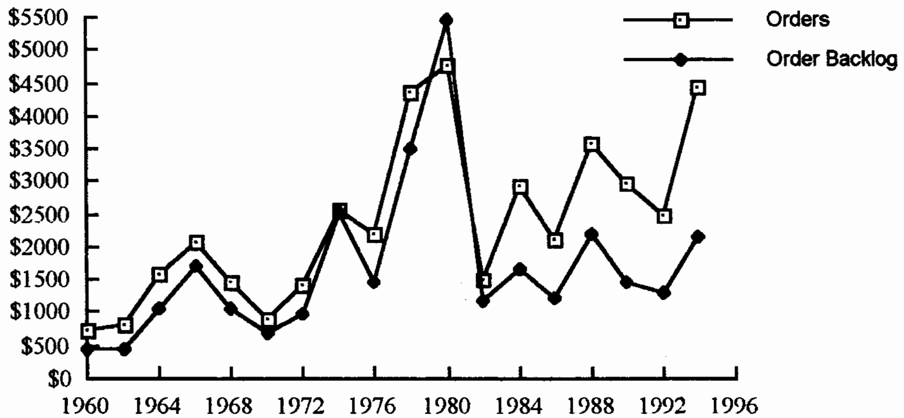


**Fig. 3.** *New orders in billions of $US and backlog of unfilled orders 1960–84.*
*Source:* US Bureau of Economic Analysis, *Business Statistics 1979* for 1960–1978, thereafter *US Survey of Current Business Patterns.*

What happened to Jones & Lamson (J&L), one of the first producers of NC lathes in the US, is instructive in demonstrating the flawed backlog strategy. In the late 1970s, J&L's order books filled up. However, they continued to build their machines on a one-at-a-time basis, making eager buyers wait more than a year to take delivery. Japanese firms, producing NC lathes with more simplified designs and on a volume basis, wrested orders from J&L (March, 1988, p. 13). According to the NRC (p. 26):

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of Bridgeport Machines, a Textron subsidiary; George Becker, CEO of Giddings & Lewis; Ralph Cross, Sr., Chairman of the Board of Cross and Trecker Corporation; Michael Davis, President of White-Sundstrand Machine Tool, a division of White Consolidated Industries; Nathaniel Howe, Vice-President, Litton Industries; and James Gray, President of the National Machine Tool Builders Association. The companies visited in Japan included the Makino Milling Machine Company, Toyoda Machine Works, Mori Seiki, Fujitsu Fanuc, Yamazaki Machinery Works, Okuma Machinery Works, and Kawasaki Heavy Industries.

The traditional practice of order backlog management, which served US machine tool builders well for several decades, was based on an implicit assumption that potential foreign competitors did not have the resources to take advantage of wide swings in the US machine tool market. Whether this assumption was ever valid, it certainly was not so by the late 1970s. By that time many foreign firms had the resources to offer fast delivery of quality machines to US customers who did not wish to wait for backlogs to be worked down by their domestic suppliers.

It became customary for US manufacturers to take delivery of Japanese machines within one to two months of the order date, while some US builders required their customers to wait one to two years for deliveries (NRC, 1983, p. 27). In a January 1997 interview with William Lyons, owner and president of Massachusetts-based Brimfield Precision Instruments, he noted that his company had always purchased US-made machine tools until the late 1970s when they had tremendous difficulty in acquiring the equipment they needed to expand their production capacity. Their machine tool distributor had just become a distributor for several Japanese companies and offered Lyons immediate delivery on two NC lathes. From then on Lyons almost always purchased Japanese machining centres because delivery times and pricing were better, the machine tools performed well and the builders provided excellent service and training.

The erratic business cycle also affected research and development expenditures. During downturns, little was done to develop new products, while in upturns builders worked feverishly to fill their back orders. Cincinnati Milacron was one exception to the general rule, and its slow, steady growth in recent years attests to its successful strategy. Top officers made a decision in the early 1970s to remain number one in technology and to focus on a core set of machine tools. Between 1972 and 1982 they boosted research expenditures each year, so that by 1983 the company invested 5.4% of sales this way. In general, large builders invested far less than this. In September of 1979, James Gray, president of the NMTBA, noted that: 'In Europe and Japan, research and development is a way of life for the machine tool industry. R & D funds come off the top. They are not a residual expense, to be invested if the money is available. As a result, our foreign competitors have generally narrowed the quality, productivity, and technology gap' (Gray quote in DiFilippo, 1986, p. 52). Managing the business cycle and 'working the backlog' occupied the time of industry leaders for most of the 1960s and 1970s. This resulted, as one industry analyst noted, in 'the deterioration of the technical superiority of the US machine tool industry' (Cincinnati Milacron, 1984; DiFilippo, 1986, p. 52; Eckley, 1991).[1]

## 4. What happened to the industry?

Two significant differences in industry approach emerge from this comparison of machine tool builders in Japan and the United States. First, Japanese machine tool firms worked together, with the encouragement and financial support of the government, to invest in NC technologies. FANUC focused on the development of controls and software, while the machine tool builders worked on the design of the machines to be operated with the new controls. Second, because the fusion of the traditional machine tool with new technologies was complex, a strategic decision was made by Japanese firms initially to perfect the technology on a series of basic milling, drilling and cutting operations. When

[1] Citing patent records, DiFilippo determined that 84% of all patents for metal-working machinery and equipment in 1963 came from the US. In 1973 the percentage fell to 68%. In absolute numbers the patents filed in 1973 were slightly higher than in 1963, indicating that foreign builders had dramatically boosted their patent filings (DiFilippo, 1986, pp. 52–3).

these tasks were mastered, and organisational learning increased, more complex operations were added. By comparison, US builders constructed complex, highly engineered and very specialised machines for their defence and automotive customers, and they did so without any serious attempt to develop an industry standard for the computer controls. Even if we assume for a moment that the US strategy could work, the question remains as to where demand would come from for the massive and expensive machine tools that were produced? The design and build path employed by Japanese firms carried with it extensive market volume possibilities among the thousands of small and medium-sized companies in Japan, the US and elsewhere around the world. Here, builders were assisted by MITI's intention to support the development of a simple, standard set of controls for basic lathe, milling and grinding machines. MITI's offer of low-interest loans to machine tool and other metal-working firms to purchase the computer-controlled equipment helped establish a domestic market for builders (Subramanian and Subramanian, 1991).

Cost was indeed a consideration for machine tool buyers. The NRC study uncovered numerous examples of design and engineering projects undertaken by the Pentagon and defence firms that resulted in high-priced technologies that no one other than a defence contractor could afford. For example, one defence contractor ordered a computerised design system in 1978 but did not actually award the bid for the equipment until 1981. By then the technology had been improved dramatically but the contractor never updated its specifications and the vendor was required to deliver an obsolete system. In another example, the government requested a group of machines costing $10 million. One of the potential vendors came up with a more efficient design to perform the same machining functions and drop the total cost of the project $4 million. However, because the contract was already written 'the government customer would not consider a new, less costly approach' (NRC, 1983, p. 67). Since tool design in such cases was not driven by cost considerations, many US machine tool builders never fully integrated cost-effective approaches onto their factory floors.

The post-Second World War history of the US industry is thus marked, first, by a failure to capitalise on the new technologies and, second, by the slow move to utilise advanced technologies once they became the industry standard. As a consequence, productivity remained stagnant during the late 1970s and 1980s. US machine tool makers have failed to increase real output per worker since the 1950s (CTI, 1994, vol. 1, p. 21). Based upon interviews with 43 US machine tool builders, the NRC concluded that managers were more concerned with the financial health of their companies than with the overall impact of technology on the industry. 'Extraordinary efforts might be required among American machine-tool builders', the committee determined, 'in order to maintain their reputation for technological excellence' (NRC, 1983, p. 41; Ashburn, 1990, p. 80). By the early 1980s, then, US firms were neither building the most technologically advanced equipment, nor were they purchasing advanced equipment and employing sound production practices to build their machines. In 1973 the US had approximately 30,000 NC tools in place, or less than 1% of its installed base of equipment. Solid-state controls became commercially available in the mid-1970s and 'first mover adoptions peaked during the 1975–79 period for domestic plants. Yet by 1983, the number of NC/CNC machines had apparently risen only to 100,000, or 5% of the installed base. In contrast, 30% of the Japanese installed base was NC/CNC tools by 1985' (March, 1988, p. 16).

US firms were thus at a distinct disadvantage when it came to competing on the basis of price and delivery with firms in Japan that both built and deployed the technology. In so doing, these firms captured the learning that resulted from their own operation of the equipment and applied it to make continuous design improvements to the machines that they built; this allowed them to stay well ahead of their global rivals. To compound the industry's difficulties their principal customers, US manufacturers, failed to understand 'the importance of being competitive internationally' and in so doing, they did not exert any pressure on tool builders to come up with design improvements. Without widespread and consistent financial and technical support from the government for technology adoption, there was very little user push or pull on machine tool firms to develop sophisticated technology applications. In Japan, to the contrary, there was a highly articulated infrastructure of innovation support in place for tool builders and their customers to utilise (Best, 1990, esp. chs. 5–6).

The US industry's failure to pay attention to the globalisation of the industry was perilous since the traditional domestic market was contracting.[1] Between 1980 and 1990 domestic purchase of machine tools declined by 37%, even as worldwide demand grew. The machine tool purchases of Pacific Rim countries grew by 104%, while countries in Europe increased their purchases by 55%. In 1990, the German and Japanese machine tool markets were more than double the size of the US market. With its home market contracting and global rivals emerging to compete for the export market and the US domestic market, firms were caught in a tightening vice. In addition, the backlog strategy remained a disincentive to engage in product research and development and the improvement of manufacturing processes. By the early 1980s firms often carried more backlogged orders on their balance sheet than the total value of their annual production, forcing customers to wait two to four years to have their orders filled (CTI, 1994, vol. 1, pp. 19–20).[2]

US companies also retreated from the development of workforce skills and suffered from a severe lack of shop-floor occupational training. US managers pursued a 'lower skill strategy' unlike their international competitors in Germany and Japan and this discouraged 'the most able young people from entering metalworking' (CTI, 1994, vol. 1, p. 44). One after another, firms ended their apprenticeship programmes, in part as a response to the cyclical nature of the business. If managers were going to survive the vagaries of the industry through massive layoffs and recalls, why invest in the workforce? Skill, and by implication historical knowledge of the manufacturing process, became expendable; machine tools, it was reasoned, could serve as substitutes for highly trained workers. And if a skilled machinist was needed, it was cheaper simply to offer more money to one from a neighbouring firm, than invest in an in-house apprenticeship programme.[3] This approach can be compared to the shop-floor strategy found among Japanese machine tool firms,

[1] The experience of one metal-working firm sums up the industry's disregard for its customers. 'I was in a shop up in the country in New York. This guy had two machines in a barn and he had an American built machine. He had a lot of trouble with it. Had trouble getting the service man to come up in the country. He bought a Japanese machine and said—they would fly a man from San Francisco over night. He would rent a car in Albany in New York and he would drive up and he did have the guy here the next day. He said: when he bought his second machine, he didn't even invite an American to bid on it' (Laske, 1996, p. 166).

[2] In the MIT study a Cincinnati Milacron executive acknowledged that 'We ignored the Japanese in machine tools, and now it's late; our attitude has changed, and we're trying not to let the same thing happen in injection molding machines for plastics.' To do so, Cincinnati Milacron has made significant changes in the ways in which it builds its machines, by establishing cross-functional design teams and reducing parts by 30% (March, 1988, p. 14).

[3] By comparison, the industry-based German apprenticeship system produces four times as many skilled machinists (on a percentage of the population basis) as the United States. US builders also employ fewer engineers than Japan (CTI, 1994, vol. 1, p. 44).

predicated upon lifetime employment, respect for workers' tacit knowledge, and the ability to create a synthesis of knowledge from various sources to resolve technical problems (Lazonick, 1990, esp. ch. 9; Moritz, 1996).

The purchase of firms by conglomerates exacerbated the erosion of shop-floor skills. Holland's history of Burgmaster reveals the arrogance of the outside owners from Houdaille who went about dismantling Burgmaster's shop-floor structure in their quest for a fast return on their investment. The company's long-time skilled machinists and engineers were not consulted and numerous failed shop-floor reorganisation campaigns were the result. Holland describes one effort of the new engineering department to purchase a $480,000 milling machine with special tools costing $50,000. The machinist slated to operate the milling machine was not consulted on the purchase of the special tools and when they arrived at the plant he determined that they were unusable. According to Holland, Houdaille's acquisition changed the plant from a structure based on knowledge and ability to one built on allegiance to the corporate way of doing things (Holland, 1989, p. 90). Burgmaster's shop floor was all too typical of shop floors in machine shops and heavy industry across America in the post-war period. 'Management and labor were less like partners in an enterprise, and more like adversaries. Management presumed that machinists disliked their work, and would avoid it if at all possible. To the extent that they could be made to work, the blue-collar work force had to be controlled or coerced' (Holland, 1989, p. 92). Japanese firms employed a superior strategy on the shop floor and placed a great deal of emphasis on the utilisation of worker skills. As the Rand study concluded: 'These chief US rivals use their own factories as test beds for the latest tools, relying on workers to come up with new incremental improvements in products or the process of making them. This includes not only engineers, but production workers as well' (CTI, 1994, vol. 1, p. 49).[1]

## 5. Conclusion

The NMTBA undertook a study of 16 large metal-working companies in 1978 and determined that the book value of their fixed assets, that is the very machines builders utilised in their own manufacturing processes, had dropped markedly between 1970 and 1977 when compared to the 1965–70 period. This failure to invest was tantamount to the industry being engaged in an 'unconscious and involuntary' process of self-liquidation (cited in DiFilippo, 1986, p. 47).[2] The NMTBA's report on their 1981 fact-finding trip to Japan was highly self-critical in its analysis of why Japan's machine tool builders appeared to be so successful. There was no 'magic bullet' that explained Japan's rapid rise to industry prominence; instead there was a serious commitment to the continuous improvement of the production process. According to the NMTBA (p. 5):

> Nowhere in the thirteen factories toured by our study group did we see any unique manufacturing technology. In general Japanese machine tool builders use the same types of machinery to build their products as in America. However, the equipment and technology are very intelligently applied and many builders are investing heavily in the latest technology to improve productivity further.

[1] For an extended discussion of the German apprenticeship system see the CTI study (1994, vol. 2, pp. 28–35). CTI makes the point that a high skill level is one of the main factors of competitiveness for German machine tool builders.

[2] According to DiFilippo, capital investments by tool builders dropped sharply in about 1970 as the Vietnam war order-boom started to dissipate. By the end of the decade capital expenditures were lower, in inflation-adjusted dollars, than they had been in 1965 (NRC, 1983, p. 47).

In the NRC study, the head of manufacturing engineering at an aerospace firm provided this succinct analysis: 'The Japanese are more likely to give you a product that will run the first time', he stated. 'US manufacturers usually give you a longer lead time, and the reliability of their machines is not the greatest' (NRC, 1983, p. 76). MIT and Rand identify several industry weaknesses, including: the small size of firms and their inability to gain any scale production advantages; over-reliance on a too narrow customer base; the cyclicality of primary customers like the automobile and aerospace industries; and lagging product innovation and internal technology and skill investments. These are not new issues. In the 1920s the American Society of Mechanical Engineers (ASME) expressed a concern that there was far too little coordinated research in the field of machine shop practices. The ASME noted that a solution to this industry weakness was the establishment of a 'central institute or laboratory to be supported by contributions from the various trade associations and individuals in the industry, but before such an institution can be established there must be an awakening to the true significance of fundamental and applied research' (Wagoner, 1968, pp. 29–30). During the Second World War government procurement agencies encouraged the standardisation and simplification of machine tool production as a way to boost output. Firms were urged to establish a programme for the 'elimination of unnecessary sizes and types, standardization of simple elements within each particular group of tool builders, and cooperative effort on the basic problems of industrial standardization' (Wagoner, 1968, p. 31). The ASME's call for research went unheeded as the Depression taxed the survival skills of the industry, while war-era efforts to promote standardisation advanced little in the 1950s when markets appeared to be secure.

Research and development expenditures remained woefully low throughout the 1960s and 1970s; estimates for the 1970s place such spending at roughly 1.6% of sales. This increased somewhat by the early 1980s, but the merger and conglomerate wave hurt the research and development process, as Houdaille, Textron, and Litton failed to invest sufficiently in the development of their CNC product lines. One independent builder interviewed for the MIT study noted that these conglomerates had no serious commitment to the industry and 'thought that they could make money by selling the same old designs and building them on depreciated equipment...' Employing this approach, they were easy targets for global competitors who built machine tools with less costly and more simplified design and build procedures (March, 1988, p. 15).

The NMTBA's cogent 1981 analysis of its Japan tour concluded that builders there were successful because of the 'willingness of management to invest heavily in its future, market its products aggressively throughout the world, work doggedly toward long-term goals, and pay an unusual amount of attention to the training and motivation of its workforce.' Tour participants praised the long-term commitment of both managers and workers to the improvement of the industry. 'Every Japanese machine tool builder's goal is market share and output volume, as opposed to profit. They will boldly sacrifice profits for several years to build the groundwork for later success.' This long-range approach to firm performance grew out of a firm's 'greater reliance on bank loans than on the sale of securities to meet its capital requirements. Thus stockholders lack power to pressure for yearly profits.' Such market development and finance strategies were supported by substantial investments in worker training and the organisation of the shop floor to encourage maximum participation from machinists in all phases of the production process (NMTBA, 1981, pp. 12–13):

Keeping their workplaces and machines in good order is a responsibility assigned to the operators themselves, along with maintaining output, helping fellow workers and assuring they every part produced meets or exceeds quality standards... each worker is trained to correct the minor problems that often arise in the course of the day, to conduct regular preventive maintenance to monitor and adjust equipment, and to search continually for ways to eliminate potential disruptions and improve efficiency.

The US industry failed to perform well in each of these areas and, as a consequence, was incapable of sustaining well-paid jobs when faced with the challenge from firms that did.

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