Good Jobs and the Cutting Edge: The U.S. Machine Tool Industry and Sustainable Prosperity

by

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Introduction

Good jobs started to disappear from the U.S. economy in the late 1970s. By good jobs I mean employment that can "provide high standards of living in terms of earnings, employment stability, and benefits for sickness and old age" (Lazonick and O'Sullivan, 1996, p. 1). The loss of the majority of these jobs resulted from structural, not cyclical problems in the manufacturing sector. A significant structural problem is the sharp decline of the U.S. machine tool industry. For much of the post - World War II period American preeminence in machine tool construction and the productivity advantages that accrued to manufacturers with access to these machines, enabled both builders and goods producers to prosper and provide well paying and stable job opportunities. But the jobs of skilled machinists were lost during the 1980s as the country passed from a net exporter, to the world's largest importer of machine tools and goods producers lost their first access to top notch production machinery and the competitive advantages over foreign producers that this equipment once purveyed. The rusting of the machine tool industry thus contributed to the hollowing out of the country's manufacturing base.

A principal focus of the paper is a comparative analysis of the development of computer numerically controlled machine tools in the U.S. and Japan. Japan's ability to wrest global machine tool preeminence from the U.S. grew out of its successful development of this technology. The first section of the paper contains a brief history of the industry and documents the decline of production and employment after 1970. Section two describes the industry's failure to resolve the problems caused by extreme new order cyclicality. Section three reviews the history of numerical control machine tool development in the U.S. and Japan. In section four and the conclusion various reasons for the industry's collapse are discussed.

II. 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 metalworking equipment sector that is an important adjunct to the machine builders.[1] Firms are contained within two U.S. 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 U.S.- built machine tools and 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 cutting machines remove metal while forming machines alter the shape of metal (see March, 1988, Appendix A for a more detailed discussion of industry technical definitions). In his history of the Burgmaster Company Max 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 19th century numerous shops employed skilled machinists and their apprentices in the manufacture of these "master machines" and were the catalyst for the country's manufacturing preeminence. In Springfield, Massachusetts the federal armory's 19th century innovations in the use of gages to insure consistency in production led to dramatic improvements in the manufacture of a host of products. The diffusion of armory best practices was fundamental to the establishment of mass production techniques. The nation's locomotive builders, builders of mill machinery and machine tool companies symbolized America's "rising technically driven society." Finished goods producers like 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. Goods 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. First access to top-notch equipment clearly gave firms a competitive advantage while the builders' collaboration 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" (Gibb, 1953; Broehl, 1959; Rosenberg, 1963; Rolt, 1965;

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

Woodbury, 1972; Cincinnati Milacron, 1984; Hounshell, 1984; Best, 1990; Forrant, 1994; Brown, 1995, p. 234 - 235; Best and Forrant, 1996).

Through World War II defense-related production stimulated the demand for machine tools. In 1939 Jones and Lamson, Fellows Gear Shipper, and Bryant Chucking Grinder collectively sold 1,486 machines, in 1943 their sales increased fivefold to 7,525 machines. But at war's end orders dissipated, caused in part by the federal government sale, at 20 cents on the dollar, of 200,000 of the 500,000 machine tools it had purchased and placed in defense plants across the country. By 1949 the total national 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 to $249 million from $424 million over the same period (Broehl, 1959; Wagoner, 1968, p. 319; Holland, 1989, p. 20, p. 282).[2] However, U.S. builders remained dominant in world markets through the 1950s, in large part because there was little global competition for sales to U.S. producers in the rapidly expanding post-war automobile, aircraft, and other durable goods sectors. In addition, several builders continued to receive lucrative contracts from the military. But by the late 1960s this global preeminence was challenged by builders in Japan and Germany and the U.S. industry's response to these pressures was technically and organizationally bereft. The industry's internal failures to respond to the global challenge help to explain the stunning collapse of the industry.

According to the 1992 federal manufacturing census there are approximately 650 machine tool firms in the U.S. Hundreds of these companies are small and family-owned while only 88 employ more than one hundred people. The typical family-owned or closely held firm employs ten to fifty 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 produce only a few machines each year, have difficulty gaining any production advantages through the deployment of computer technologies and are constrained in their ability to raise capital. Large firms, including Cincinnati Milacron, Litton Industries, Ingersoll-Rand, Monarch Machine Tool and Giddings and Lewis account for close to 70 percent of total industry sales. Many of these 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

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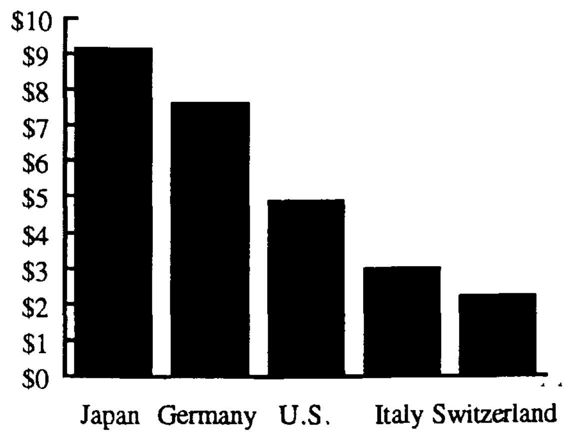
2 Just before the end of the Korean War the U.S. Office of Defense Mobilization put forward a plan to stabilize the machine tool industry to avoid the terrible slump that followed World War II. It was recommended that the government purchase $500 million worth of machine tools a year, but this did not 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).

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, more recent 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.[3]

The U.S. produced $3.6 billion worth of machine tools in 1982, thereafter production declined steadily before it slowly increased and it was not until 1994 that output exceeded the 1982 figure. In 1995 $4.9 billion worth of machine tools was shipped. The slight increase in U.S. sales resulted from the growth in the purchase of machine tools by U.S. manufacturers as they emerged from the early 1990s recession. But according to *Metalworking Insiders Report,* U.S. growth could have been substantially higher had the industry not lost production capacity from closings and consolidations. As a consequence, the growth in domestic demand was satisfied by a steady increase in imports.

Figure 1: Top Five Producer Nations in 1995



The production increase was part of a worldwide recovery in the industry. A comparison of the top five producer nations in 1995 is contained in Figure 1. According to the *Metalworking Insiders*

[3] 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 U.S. company (NRC, 1983, p. 44).

Report the total dollar value of the output of the 37 major machine producing countries increased by 30 percent 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 percent over 1994.[4] Based on total 1994 sales, 56 of the top 200 machine tool firms in the world were Italian, 49 were German, 44 were Japanese, and 25 were U.S. (The Association for Manufacturing Technology, 1996b). In 1995 the U.S. imported nearly six time more machine tools by dollar value than did Japan (Tsuji, Ishikawa, Ishikawa, 1996, p. 31, p. 35). The ten largest builders by sales volume are listed in Table 1, of these six are Japan-based. By 1995, the U.S. imported nearly six time more machine tools by dollar value than did Japan (DiFilippo, 1986, p. 7; Critical Technologies Institute {CTI}, 1994, vol. 1, p. 11 - 12; Association for Manufacturing Technology, 1996a; Tsuji, Ishikawa, Ishikawa, 1996, p. 31, p. 35).

Table 1. Ten largest machine tool builders in 1994 by sales in millions of dollars U.S.

Company	Country	Sales
Amada	Japan	845.6
Yamazaki Mazak	Japan	732.1
FANUC	Japan	730.0
Fuji Machine	Japan	617.2
Giddings and Lewis	U.S.	557.3
Western Atlas	U.S.	502.0
Okuma Machinery Works	Japan	471.1
Mori Seki	Japan	440.5
Schuler Group	Germany	417.2
Thyssen Maschinenbau	Germany	416.8

A significant feature of Japan's growth, and one that demonstrates its global strength, is the fact that foreign demand led the recovery there, unlike in the U.S. where exports fell. Japanese firms dominate in the global sale of computer numerical control machining centers, and Japan-based FANUC is 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 U.S. Big Three automobile assemblers, a cut in defense procurement and the overall decline in several categories of

[4] Japan's output accounted for one-quarter of total world production in 1995. Machine tool output rose 43 percent in dollar value in Germany between 1994 and 1995 as it emerged from the European recession. Italy increased production 31 percent and ranks fourth in world production and fourth in exports behind Japan, German, and the United States. Western European nations currently produce 44 percent, and Asian nations 38 percent of the world's machine tools.

domestic manufacturing, 600 of the 900 U.S. machine tool builders with fewer than 20 employees permanently closed their doors between 1982 and 1987. Machine tool total employment declined almost 20 percent between 1983 and 1995 as jobs fell to 57,000 from 70,000 while the number of production workers dropped almost 12 percent to 35,700 from 40,000. For comparison purposes, 1967 total employment was close to 120,000 (see Table 2) .

Table 2. U.S. Employment in Thousands in the Machine Tool Industry 1975 - 1995

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*

Where did the markets go? There are two principle ways for machine tool firms to increase 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 with more effective technology. In the U.S., the strongest post -World War II expansions in the industry were related to the military demands of the Korean and Viet Nam wars. At other times replacement demand was modest as goods producers tended to keep machinery in production for fifteen to twenty-five year periods (Holland, 1989, p. 283). Through the early 1980s the Department of Defense directly or indirectly purchased 20 percent of the industry's output. DOD direct purchases were approximately 4 percent in the 1970s and 7 percent in the early 1980s. A 1983 study completed by Data Resources, Inc. (DRI) for the National Machine Tool Builders Association analyzed all direct and indirect purchases by the DOD. Indirect purchases included tools for arsenals, prime contractors, shipyards, and tools purchased by defense contractors and subcontractors for use in the production of weapons. From this data DRI concluded that "by conservative estimate, up to 20 percent of the aggregate domestic consumption of machine tools is related to defense needs, even in peacetime" (cited in NRC, p. 54). Machine builders also depended on the vicissitudes of demand from the automobile industry. In the 1970s the automobile industry consumed 28 - 30 percent of domestic machine tool orders. The automobile industry' captured the attention of several machine tool builders in the mid-West. But like defense, these machines had little application for anything other than the automobile industry, and here too, purchases were cyclical (Wagoner, 1968, p. 92 - 93; Noble, 1986). As a consequence of their focus on defense and automobiles, machine tool firms derived only a minimal transfer of engineering and production knowledge to the development of machines for other sectors.

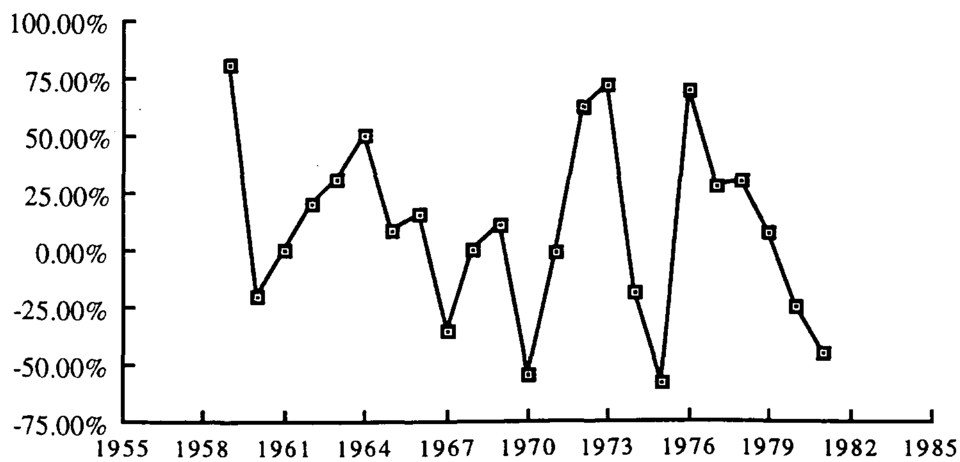
The dependence on defense and auto sales might not have been a significant problem had three things remained constant: first, the defense and automobile industries, in spite of their ups and downs, continued to grow; second, there was little or no international competition in the production of more general purpose machine tools; and third, the pace of machine tool innovation remained slow; however, none of this held true by the mid-1960s. After out-pacing the world in the 1950s and 1960s machine tool builders went through a period of sharp decline as a consequence of heightened international competition and numerous management missteps, including a failure to invest sufficiently in product and process developments, an inability to manage erratic business cycles, a failure to capitalize 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 workforce development.

In summary, of the approximately 650 machine tool firms in the U.S., just 30 employ more than 250 people, and 467 employ fewer than 50 people. These large firms have the opportunity to take advantage of the manufacturing cost savings that can result from production scale. However, as will be discussed, firms did not organize their manufacturing activities to gain these scale advantages. And with a few notable exceptions, small firms failed to collaborate in the same ways that small and medium-size machine tool firms did in other regions of the world, like Baden Wurttemberg in Germany, Piemonte and Lombardia in Italy, and the Basque Region of Spain. The lack of scale advantages, the inability of small firms to work together to accrue scale-like advantages and an over-reliance on defense and automobile customers hampered the industry in the face of global competition (Pyke and Sengenberger, 1992; Laske, 1996; Forrant and Flynn, forthcoming).

II. The Failure to Manage Industry Cyclicality

After World War II the U.S. machine tool industry suffered from extreme new order cyclicality (DiFilippo, 1986, p. 89 - 93; Corcoran, 1990, p. 230). 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 orders decreased almost 50 percent compared to 1955, followed by an increase of 75 percent in 1958; an order increases of almost 90 percent between 1970 and 1972 was followed by a drop to pre-1970 levels between 1973 and 1975. Figure 2 charts the percentage change in new orders from the late 1950s to the early 1980s.

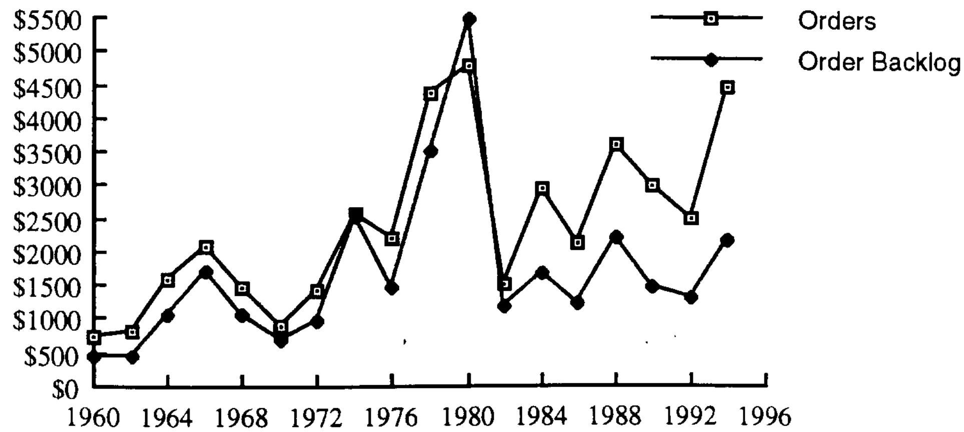
Figure 2. Percentage Change in Yearly New Orders in the U.S. Machine Tool Industry 1958 - 1982



Sources: National Machine Tool Builders *1984 - 1985 Economic Handbook.* Data table in DiFilippo, 1986, p. 90.

Absent global competition U.S. firms endeavored to manage these order fluctuations at the expense of their customers by maintaining inordinate backlogs of work; for some builders shipments lagged two to three years behind orders. Max Holland found that when Burgmaster introduced a series of new NC machines in 1964 orders increased to $16 million from $8.4 million in one year while shipments increased 18 percent. By January 1966 Burgmaster had a backlog for the new equipment of $30 million, yet it shipped roughly $900,000 worth of machines each month. As a consequence, unhappy customers waited up to two years to take delivery on the machines they desperately needed to boost their own output. The backlog strategy alienated customers and left builders vulnerable to any competitors capable of producing low-cost, high-quality equipment that could be delivered on time (March, 1988, p. 12, p. 106 - 107). Figure 3 shows orders and order backlogs between 1960 and 1994.

Figure 3. Annual New Orders in Billions of Dollars U.S. and Backlog of Unfilled Orders 1960 - 1984



Source. U.S. Bureau of Economic Analysis, *Business Statistics 1979* for 1960 -1978 thereafter U.S. *Survey of Current Business Patterns*

What happened to Jones & Lamson (J&L), one of the first producers of NC lathes in the U.S., is instructive in demonstrating the failed backlog strategy. In the late 1970s J & L's order books filled up for their NC lathes but they continued to build the in-demand machines on a one-at-a-time basis, making eager buyers wait at least a year to take delivery. Producing NC lathes on a volume basis and with more simplified designs, Japanese firms wrested orders from many of J & L's disgruntled customers. (March, 1988, p. 13). In a January 1997 interview with William Lyons, owner and president of Brimfield Precision Instruments, he noted that his company always purchased U.S. made machine tools until the late 1970s when they had tremendous difficulty acquiring the equipment they needed to expand their production capacity. Brimfield's machine tool distributor had just become a distributor for several Japanese machine tool companies and offered Lyons immediate delivery on two NC lathes. From then on Lyons, almost always purchased Japanese machining centers because delivery times and pricing were better and the machine tools performed well. Japanese builders also provided excellent service and training. Using industry surveys the NRC determined that:

The traditional practice of order backlog management, which served U.S. 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 U.S. 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 U.S. customers who did not wish to wait for backlogs to be worked down by their domestic suppliers (p. 26).

The surge in the importation of machinery from Japan mirrored the mid-1970s build-up of unfilled orders in the U.S. and made it possible for Japanese builders to make the necessary investment in equipment and shop floor organization to increase their productivity and build lower-cost machines. To simplify the assembly process, and cut the build-time and cost of their machine tools, firms in Japan made three important production changes. 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 U.S. firms began to work to drive down costly machine set up times, Japanese firms were well on their way to entirely eliminating many set ups through the redesign of machines. Third, since the machine tools were designed with fewer total parts, this simplified assembly and therefore decreased assembly time (Japan Society, 1994). All of these changes lowered production costs and equally important time-to-market.[5]

The erratic business cycle also affected industry 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 attests to a more successful strategy. Its top officers made a decision in the early 1970s to stay number one in technology. Between 1972 and 1982 they boosted research expenditures each year so that in 1983 the company invested 5.4 percent 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).

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[5] The 1981 study tour of U.S. 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, 22).

Managing the business cycle rather than improving the production process occupied the time of industry leaders for most of the 1960s and 1970s and this resulted in "the deterioration of the technical superiority of the U.S. machine tool industry" (Cincinnati Milacron, 1984; DiFilippo, 1986, p. 52).

III. Machine Tools and the Innovation Dynamic

The U.S. machine tool industry's principle customers in aerospace, automobiles and nonelectrical machinery had growth rates of only about 2 percent 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 .6 percent per year from 1977 through 1986, their production declined by ten times that rate. The contraction is accounted for by the rise in 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 20th 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 that worked in close, consultative relationships. For instance, the demands posed by early 20th 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 specialized 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 U.S. manufacturing success dating back to the Springfield Armory and the spread of various gaging techniques to insure 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 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 characterizes 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 design, build and utilization 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 toward 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 U.S. 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 U.S. and Japan took quite different paths as they developed computer controls for machine tools It is not an exaggeration to state that the epicenter of Japan's late 20th century manufacturing advantage is its successful development of computer controls for a wide array of machine tools suitable across numerous industries. It is not an exaggeration to argue that the flawed efforts of U.S. machine tool builders, linked directly to large-scale research projects funded by the Defense Department and prime defense contractors greatly contributed to the weakened overall state of the U.S. industry and by extension manufacturers who relied on gaining access to first-class production equipment. In the post-World War II period in the U.S. 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, U.S. manufacturers were not purchasing new machine tools, thus slowing innovation demand-pull. In 1973, 33 percent of machine tools in use in the U.S. were less than ten years old, as compared to 60 percent in Japan. By 1978, 40 percent of U.S. machines were over 20 years old, while in Japan the figure was just 18 percent. This not only hurt machine tool sales, but it hindered manufacturing productivity and competitiveness as it meant that U.S. manufacturers were competing with Japanese producers operating with newer technologies. Even the average age of the machine tools utilized 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, p. 16 - 18; NRC, 1983, p. 2).

In the late 1950s U.S. industry leaders did take notice of Japanese machine tool builders but dismissed them as unworthy rivals for world-wide 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 specialized 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 U.S. 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 U.S. (*American Machinist*, June 1,1959).

After World War II 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 association, successfully directed their attention to the development of appropriate computer controls for these basic machine tools global sales expanded, particularly to the U.S. where manufacturers eagerly purchased these machine tools. By the 1980s the U.S. 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. Forty-one percent of these imports came from Japan in the form of computer numerically controlled machining centers and lathes.[6]

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.[7] In 1952 MIT demonstrated its control system on a Cincinnati Machine Tool 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, p. 46 - 47).

To confound the MIT project 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 sold their controllers on the market, but with only limited success, partially because each firm's system

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6 In 1995 Japan, Germany, Switzerland, Italy, Taiwan and Spain had a positive trade balance in machine tools, while Korea, China, and the U.S. ran trade deficits. The U.S. 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. U.S. 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 percent to 22.2 percent during these same years (National Machine Tool Builders Association, *Economic Handbook*, 1987.

7 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 already used by companies like Burgmaster, to instruct machine tools to perform simple drilling and milling procedures (Holland, 1989, p. 284; Noble, 1986).

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 rang of machine tools, and competing firms control units were incompatible" (Collis, 1988b, p. 11). Thus, equipment integration 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 program 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, p. 47 - 48).

In his history of the Burgmaster Company Max 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 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 subsidized, scant attention was paid to cost controls and thus machines were built that were in Holland's words "far more sophisticated than anything a civilian manufacturer might need, or be willing to pay for" (Holland, 1989, p. 34 - 35). 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 was forced to subsidize commercial development by purchasing one hundred five-axis continuous-path profile milling machines, twenty-five each from Cincinnati Milling, Giddings & Lewis, Kearney & Trecker and Morey Machine.

Compare this history to Japan's , where early on in the promotion of NC technology controls built by Fujitsu Automatic Numerical Controls (FANUC) became the recognized 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 twenty-eight machine tools was being operated with controls built by

FANUC.[8] 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 center in the U.S. to boost exports (Mealey, 1974, p. 31 - 34).

How was this possible, when U.S. 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 forty 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, 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. 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.[9]

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 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 World War II. Licensing agreements with foreign machine tool companies were brokered by MITI, while direct foreign investment in Japanese machine tool firms was

[8] FANUC started as a division of electronics giant Fujitsu and competed with several U.S. 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 license (Critical Technologies Institute, 1994, vol. 2, p. 108).

[9] 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, Ishikawa, 1996, p. 5).

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, Toshiba Machine Company and Toyoda Machine Works. The U.S. 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 U.S. firms included: Koyo and Van Norman to build centerless grinders; Toshiba Machine and Kearney & Trecker to build transfer machines; Sansei and Bryant to build centerless grinders; and Murata and Warner Swasy to build a variety of machines. Countries with the most agreements were the U.S. with 67, West Germany with 33, France with 32 and Switzerland with 18 (Chokki, 1986, p. 131 - 132, 134; Tsuji, Ishikawa, Ishikawa, 1996, p. 22).

For a time these licensing agreements provided an opportunity for U.S. firms to gain entry to the Japanese market. Burgmaster signed one such agreement with Chukyo Denki, a Nagoya-based machine tool firm in 1962. In the past Burgmaster 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 into U.S. sales in Japan as exports fell 50 percent in 1963 and an additional 50 percent in 1965. But in the midst of large order backlogs caused by the demands of the Viet Nam war, American builders paid scant attention to this drop off, while as ominous, and as unnoticed, Japan's machine tool exports to the U.S. skyrocketed to $26.2 million in 1967, up from $2.4 million in 1964. Chokki downplays the importance the licensing law, arguing that the resultant production and sales capacity was minimal. But it may be the case that when the law was enacted sales was of secondary importance when compared to the gains in technical knowledge that could result.

Under the Temporary Measures for the Development of the Machinery Industry Law twenty-one industries were selected by the Ministry of International Trade and Industry (MITI) for modernization 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 specialize, and it helped machine tool builders to standardize their parts across a number of machines to reduce their production costs. As a result, firms specialized 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, Ishikawa, 1996, p. 9).[10] 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 turn around of the industry, the firms themselves embarked on their own aggressive modernization campaigns, using MITI programs 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 "organized 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 organizational 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).[11]

In summary, during the development of computer controls U.S. builders focused most of their research and development efforts on solving Pentagon-related problems. The Pentagon influenced what was designed 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 customized machines influenced the direction that many U.S. machine tool firms took, and raised design and build costs without affecting performance significantly. The NRC determined that such custom design requests often diverted scarce engineering and management time to

[10] 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.

[11] 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 previous. MITI's original plan was for the industry to spend about $167 million on new capital investments; by 1960 the figure was $492 million.

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, standardization, miniaturization, and systematization 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 know-how.

The expanded market share provided by the successful development of computer-based machine tool technologies allowed Japan's machine tool firms to make continual investments in automated equipment and assembly systems to increase their productivity and build lower-cost machines. At the same time access to world-class machine tools gave production advantages to 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 U.S. 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 form 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. Toyoda Machine Works, for example, began to manufacture large numbers of machine tools for Toyota Motors which owned 24.9 percent of Toyoda Machine Works stock, while Toshiba Machine built machines for Toshiba Corporation, owner of 50.1 percent of Toshiba Machine stock. Along with these customer links, several machine tool builders gained access to financing from the major bank in their keiretsu (Chokki, 1986, p. 138; Sarathy, 1989).

The rapid growth in demand for NC machine tools meant that builders capable of producing such equipment in a timely manner received a tremendous sales boost. For the size of the U.S. domestic market see Table 3. In 1979 computer-controlled machine tools comprised just 9 percent of unit output in Japan and 2 percent in the U.S. By 1991 these output figures were 42 percent and 7 percent respectively (Friedman, 1988, p. 124; March, 1988; CTI, 1994, vol. 2, p. 13). With small and medium-sized CNC lathes and machining centers representing about 30 percent 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. On the other hand, the loss of major portions of its own sizable domestic market seriously damaged the financial position of U.S. firms. In 1984, for example, NC turning machines and machining centers comprised 25 percent of the value of machine tools built here and 42 percent of the value of imported machine tools. Using Manufacturing Census data and reports

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)

from the NMTBA Ashburn determined that by the mid 1980s all types of NC were accounting for almost half the U.S. consumption of machine tools. Yet, the 1991 total dollar value of U.S. production of this type of machine was lower than it was in 1982 even as the dollar value of the market for the technology in the U.S. stood at $2.2 billion in 1991, up from $1.25 billion in 1983 (Ashburn, 1990, p. 5; CTI, 1994, vol. 1, p. 15; vol. 2, p. 5, p. 104).

IV. 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 to initially perfect the technology on a series of basic milling, drilling and cutting operations. When these tasks were mastered, and organizational learning increased, more complex operations were added. By comparison, U.S. builders constructed complex, highly engineered and very specialized machines for their defense 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 U.S. 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 U.S. and elsewhere around the world. Here, builders were assisted by MITI's strategy to develop 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 metalworking firms to purchase the new equipment helped to 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 defense firms that resulted in high priced technologies that no one other than a defense contractor could afford. For example, one defense contractor ordered a computerized 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 U.S. machine tool builders never fully integrated cost effective approaches onto their factory floors.

The post-World War II history of the U.S. industry is thus marked by a failure first to capitalize on the new technologies and second, the slow move to utilize advanced technologies once they became the industry standard. As a consequence productivity remained stagnant during the late 1970s and 1980s. U.S. 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 U.S. 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 U.S. 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 U.S. had approximately 30,000 NC tools in place, or less than one percent of its installed base of equipment. Solid-state controls became commercially available in the middle 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 percent of the installed base. In contrast, 30 percent of the Japanese installed base was NC/CNC tools by 1985" (March, 1988, p. 16).

U.S. 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 there principal customers, U.S. 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 utilize (Best, 1990, esp. chs. 5 - 6).

The failure to pay attention to the globalization of the industry was perilous since the traditional domestic market was contracting.[12] Between 1980 and 1990 domestic purchase of machine tools declined by 37 percent, even as world-wide demand grew. The machine-tool purchases of Pacific Rim manufacturers grew by 104 percent, while European firms increased their purchases by 55 percent. In 1990, the German and Japanese machine tool markets were more than double the size of the U.S. market. With its home market contracting and global rivals emerging to compete for the U.S. domestic market, firms were caught in an ever-tightening vise. At the same time the backlog strategy was a disincentive to engage in research and development, as by the early 1980s builders often carried more

[12] The experience of one metalworking 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 inflight an American to bid on it" (Laske, 1996, p. 166)

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, p. 19 - 20).[13]

During the 1970s and 1980s tool builders retreated from the development of workforce skills and suffered from a lack of shop floor occupational training. U.S. 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 programs, 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 to simply offer more money to one from a neighboring firm, than invest in an in-house apprenticeship program.[14] This approach can be compared to the shop floor strategy found among Japanese machine tool firms, predicated upon lifetime employment, respect for worker 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 longtime skilled machinists and engineers were not consulted and numerous failed shop floor reorganization 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

13 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 percent (March, 1988, p. 14).

14 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. U.S. builders also employ fewer engineers than Japan (CTI, 1994, vol. 1, p. 44).

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 utilization of worker skills. As the Rand study concluded: "These chief U.S. 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).

In the 1983 NRC study the head of manufacturing engineering at an aerospace firm provided this quite succinct analysis of the industry: "The Japanese are more likely to give you a product that will run the first time," he stated. "U.S. manufacturers usually give you a longer lead time, and the reliability of their machines is not the greatest" (NRC, p. 76). The MIT Commission and the Rand report also 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 their concern that there was 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, pp. 29 - 30). During World War II government procurement agencies encouraged the standardization and simplification of machine tool production as a way to boost output. Machine tool firms were urged to establish a program 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, p. 31). The ASME's call for research went unheeded as the

Depression taxed the survival skills of the industry, and war-era efforts to promote standardization and manufacturing simplification advanced little in the 1950s when markets seemed so secure.

V. Conclusion

The NMTBA undertook a study of sixteen large metalworking companies in 1978 and determined that the book value of the fixed assets of the sixteen, that is the very machines builders utilized in their own manufacturing processes, had dropped markedly between 1970 and 1977 when compared to the 1965 - 1970 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).[15] 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.

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. "U.S. 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

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[15] 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).

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, p. 29 - 30). During World War II government procurement agencies encouraged the standardization and simplification of machine tool production as a way to boost output. Firms were urged to establish a program 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 standardization 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 percent 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 report of its 1981 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 organization of the shop floor to encourage maximum participation from machinists in all phases of the production process (NMTBA, 1981, p. 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 U.S. industry did not perform well in these areas, and as a consequence was incapable of sustaining well-paying jobs when faced with the challenge from those firms that did.

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