The Decline of the U.S. Machine-Tool Industry and Prospects for Its Sustainable Recovery

Volume 1

David Finegold, Keith W. Brendley, Robert Lempert, Donald Henry, Peter Cannon, Brent Boultinghouse, Max Nelson

Critical Technologies Institute
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Prepared for the Office of Science and Technology Policy

Critical Technologies Institute
This report describes the findings of the Machine Tool Study, a congressionally mandated research project examining the competitiveness of the United States machine-tool industry. The study was sponsored by the White House Office of Science and Technology Policy (OSTP) and is being conducted by the Critical Technologies Institute (CTI).

The broad approach we have taken to the analysis of the machine-tool industry should make this report of interest to a wide audience. Federal and state policymakers interested in questions of industrial competitiveness, technology development and transfer, and the adequacy of the U.S. skill base will find the review of existing policies in Chapter Six very relevant. Researchers working on the machine-tool industry in particular, or manufacturing more generally, can make use of the large amount of data presented in the main report and supporting appendices.1 And machine-tool makers themselves may benefit from the descriptions of successful corporate strategies in Chapter Five and the identification of key future technology trends in Appendix F.

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- improve understanding in both the public and private sectors of the ways in which technological efforts can better serve national objectives.

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1The appendices are contained in a companion volume (Finegold, ed., 1994).
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Machine tools are a small but vital sector of manufacturing. Close links between the makers of metal-cutting and forming equipment and the users of their tools can facilitate process innovations that raise productivity and sustain industrial competitiveness. Without a healthy domestic machine-tool industry, manufacturers may face a one- to two-year time lag in obtaining the latest production technology.

Entering the 1980s, the United States was the largest producer of machine tools, with 20 percent of the world market. It had developed the technology—computer numerical control (CNC)—that was to transform the industry. By the end of the decade, the U.S. machine-tool industry was less than half the size of those of Japan and Germany. More than two-thirds of U.S. machine-tool firms had closed, and the U.S. government resorted to protectionism to defend portions of its domestic market. What explains the decline? What can U.S. government policymakers do in response?

Our analysis demonstrates that the U.S. machine-tool industry's decline in the early 1980s was precipitated by four factors:

- The industry was overdependent on a declining U.S. market.
- The U.S. machine-tool makers' strategy for coping with cyclical demand—accumulating orders during booms and working them off during recessions—backfired, as imports gained U.S. market share by delivering in weeks rather than months.
- Japan became the world productivity leader by combining a new product technology (reliable, standardized CNC tools) with a major process innovation (modular production).
- The value of the dollar was high relative to other major currencies during this period.

These factors do not, however, explain the industry's failure to adjust to the new competitive conditions and to regain market share as the value of the dollar fell substantially starting in the mid-1980s. The failure to rebound reflects, instead, a more fundamental change. Two trends—the rapid change in machine-tool technology and the move to truly global competition—have permanently altered the basis of competitive advantage in this industry. New capabilities are required to compete, but the U.S. machine-tool industry has faced a number of structural barriers that
have hindered this adjustment. Among the United States’ weaknesses relative to Japan, Germany, and Italy (detailed in Chapter Four) are the following:

- A sector that features neither a critical mass of large firms nor cooperation among small companies needed to finance new investments
- A fragmented controller industry with no recognized standard like Japan’s FANUC
- Difficulty obtaining capital required to upgrade production capabilities or finance sales
- An inadequate skill supply and disincentives for firms to invest in training
- Weak links between the major research institutions (federal labs, universities) and the firms responsible for commercializing new technologies
- Domestic users that have, with the exception of the aerospace industry, been slow to demand the latest technologies or build links with machine-tool makers
- An inadequate export infrastructure.

After years of inaction, federal and state governments and the firms themselves have begun to address many of these problems (Chapter Six reviews recent policies). While these initiatives have not yet solved many of the structural problems, the fortunes of the remaining U.S. machine-tool makers are brighter than at any point in the last decade. They are benefiting from the results of internal restructuring, a recent surge in domestic demand, and deep crises in their chief rivals: Japan and Germany (see Chapter Five). In addition, Japan’s lead in CNC controllers is beginning to erode, and the United States has the research lead in a number of technologies that should be crucial to machine-tool makers over the next several years.

To turn this technological lead into market success that lasts beyond the current investment boom, additional changes are required in both the industry itself and in government policy. Based on our findings, we suggest a three-part strategy for revitalizing the U.S. machine-tool industry:

- Improve the rate and effectiveness of technology adoption by fostering local cooperative networks that can provide a package of services beyond the capacity of most individual companies.
- Increase investment in the manufacturing infrastructure (e.g., basic research, transferable skills) and give greater emphasis in federal research and development to production processes and building closer ties between research institutions and firms.
- Shift the trade policy emphasis from protecting the domestic market to creating a more supportive climate for U.S. exports; a global presence is crucial if U.S. machine-tool firms are to prosper in the long term.

The specific set of policy options needed to implement this strategy, along with a more thorough summary of the industry’s problems, is described in Chapter Seven.
One of the main conclusions of our analysis is that the problems of this sector are best addressed by a wider effort to improve manufacturing process technologies in the United States that will bring together the makers and users of machine tools.
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<td>AMT</td>
<td>Association of Manufacturing Technology</td>
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<tr>
<td>ARPA</td>
<td>Advanced Research Projects Agency</td>
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<td>ATP</td>
<td>Advanced Technology Program</td>
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<td>BMFT</td>
<td>Ministry of Research and Technology [Germany]</td>
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<tr>
<td>CAD</td>
<td>Computer-aided design</td>
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<td>CAMP</td>
<td>Cleveland Advanced Manufacturing Program</td>
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<td>CAT</td>
<td>Center for Advanced Technologies</td>
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<td>CECIMO</td>
<td>[Italian machine-tool industry association]</td>
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<td>CGLG</td>
<td>Council of Great Lakes Governors</td>
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<tr>
<td>CIM</td>
<td>Computer integrated manufacturing</td>
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<tr>
<td>CNC</td>
<td>Computer numerical control</td>
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<td>COCOM</td>
<td>Coordinating Committee on Multilateral Export Controls</td>
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<td>CPS</td>
<td>Current Population Survey</td>
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<td>CRADA</td>
<td>Cooperative Research and Development Agreement</td>
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<td>DM</td>
<td>Deutschemark(s)</td>
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<tr>
<td>DoD</td>
<td>Department of Defense</td>
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<tr>
<td>DOE</td>
<td>Department of Energy</td>
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<td>ERIM</td>
<td>Environmental Research Institute of Michigan</td>
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<tr>
<td>ETP</td>
<td>Employment Training Panel</td>
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<tr>
<td>FCCSET</td>
<td>Federal Coordinating Council for Science, Engineering, and Technology</td>
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<tr>
<td>FMS</td>
<td>Flexible manufacturing system</td>
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<tr>
<td>FY</td>
<td>Fiscal year</td>
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<tr>
<td>GE</td>
<td>General Electric</td>
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<td>IMW</td>
<td>Intelligent Machining Workstation</td>
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<td>ISO</td>
<td>International Standards Organization</td>
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<td>ITC</td>
<td>Investment tax credit</td>
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<td>JMTBA</td>
<td>Japan Machine Tool Builders Association</td>
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<td>MAEC</td>
<td>Manufacturing Application and Education Centers</td>
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<tr>
<td>ManTech</td>
<td>Manufacturing Technology</td>
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<tr>
<td>MITI</td>
<td>Ministry of International Trade and Industry [Japan]</td>
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<tr>
<td>MTC</td>
<td>Manufacturing Technology Centers</td>
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<td>MTI</td>
<td>Machinist Training Institute</td>
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<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
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<td>NC</td>
<td>Numerical control</td>
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<td>NCMS</td>
<td>National Center for Manufacturing Sciences</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>NGC</td>
<td>Next Generation Controller</td>
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<td>NIC</td>
<td>Newly industrialized countries</td>
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<td>NIST</td>
<td>National Institute of Standards and Technology</td>
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<td>NSF</td>
<td>National Science Foundation</td>
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<td>NSTC</td>
<td>National Science and Technology Council</td>
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<td>NTB</td>
<td>Nontariff barriers</td>
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<td>NTMA</td>
<td>National Tooling and Machining Association</td>
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<tr>
<td>OSTP</td>
<td>Office of Science and Technology Policy</td>
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<tr>
<td>R&amp;D</td>
<td>Research and development</td>
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<tr>
<td>SBA</td>
<td>Small Business Administration</td>
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<tr>
<td>SEMATECH</td>
<td>Semiconductor Manufacturing Consortia</td>
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<tr>
<td>SIC</td>
<td>Standard Industrial Classification</td>
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<tr>
<td>SME</td>
<td>Small- and medium-sized enterprises</td>
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<tr>
<td>SPC</td>
<td>Statistical process control</td>
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<tr>
<td>TRP</td>
<td>Technology Reinvestment Program</td>
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<tr>
<td>VDMA</td>
<td>[German machine-tool trade association]</td>
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<tr>
<td>VRA</td>
<td>Voluntary Restraint Agreement</td>
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The story is now a familiar one: The United States was the world leader in basic technological research and sales of a major product. But within a decade, Japanese and German firms took the technology that the United States had invented and found ways to produce it more effectively. The United States was reduced to a relatively minor player in the industry, less than half the size of Germany and Japan, and forced to erect trade barriers to defend its home market. In this case, the product is not a consumer good like motorcycles or televisions, but one that is used to make thousands of other products: machine tools.

Because machine tools are so central to manufacturing, the decline of the U.S. machine-tool industry in the 1980s was seen by many as a symbol of the broader decline in U.S. industrial competitiveness. And recently, as the decade-long decline in this industry has shown signs of reversing, the fortunes of this small sector are again being cited as a harbinger of the restoration of U.S. manufacturing leadership (Nauss, 1994).

Our analysis suggests, however, that, while the remaining U.S. machine-tool firms are more competitive than they were a decade ago, it would be dangerous to read too much into this short-term recovery, which has been spurred by the major increase in U.S. capital spending. The current boom may mask continuing structural weaknesses; indeed, there are signs that the same pattern that began the decline in the early 1980s—a sharp increase in demand followed by a surge in imports—is being repeated. The remainder of this report analyzes the reasons for the decline of the U.S. machine-tool industry and what policies may be pursued to sustain the current recovery.

WHY STUDY THE MACHINE-TOOL INDUSTRY?

It is legitimate to ask why we should study the competitiveness of the U.S. machine-tool industry and whether the U.S. government should devote any special attention to this sector.\textsuperscript{1} With less than $4 billion in 1992 annual sales, the entire U.S. machine-tool industry, if controlled by one company, would not make the Fortune

\textsuperscript{1}A study of the machine-tool industry was mandated by Congress in the legislation that created the Critical Technologies Institute in 1992.
100; it employs fewer than 60,000 people. Yet there are a number of reasons why, despite its small size, the machine-tool industry merits close policy analysis.

**Critical to Broader Manufacturing Competitiveness**

The Chinese call machine tools “mother machines” because of the crucial role they play in the manufacturing process (Miao, 1993). Machine tools are essential for reproducing the technologies required in an industrial economy. Consequently, improvements in machine-tool technology can have dramatic effects on overall manufacturing performance. In one southern U.S. factory, for example, four new flexible machining centers replaced roughly 100 conventional machines, producing major savings in production time and labor costs (Rosenfeld, 1992, p. 98).

The benefits from improvements in machine-tool technology do not in themselves justify a concern with the existence of a specifically U.S. machine-tool industry, however; U.S. manufacturers could easily buy their tools from other countries, as many currently do. But there is a risk that, without healthy domestic machine-tool makers, U.S. manufacturers will not have access to the latest technology. This need not result from any conspiracy to deny the United States access to these tools, but rather because machine-tool makers worldwide tend to first sell their most current product lines close to home to ensure that any problems are easily fixed. A 1990 machine-tool study at General Motors noted that: “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 been with BMW for a year and a half” (Chaponniere, 1990). Industry experts interviewed for this study confirmed this one- to two-year time lag.

The importance of a strong domestic machine-tool industry also increases as manufacturers focus more closely on process innovations as a vital source of sustained competitiveness (Alic et al., 1992). Close proximity between machine-tool makers and users can aid in developing new tools tailored to specific customer needs and can smooth the introduction of these tools onto the shop floor, as machine-tool makers help train workers and debug new equipment (Gertler, 1993). For example, in the plastics industry, which has replaced many applications of traditional metal-cutting and -forming tools, close cooperation between the plastic-machinery makers, the producers of plastic bottles, and the soft-drink firms has enabled the United States to remain a world leader.2

**National Security**

The vital role which machine tools play in defense production has prompted a longstanding federal government policy of supporting advanced research in machine-tool technology and maintaining a domestic machine-tool capacity in the event of war.3 While the justification for this policy may have been reduced by the end of the

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3 The Buy American Act requires that at least 51 percent of the contents of tools purchased by the Department of Defense be domestic.
Cold War, the rapid erosion of the U.S. machine-tool industry in the early 1980s has raised concerns that the United States cannot maintain a viable defense production base without a core of sophisticated domestic machine-tool makers.

**A Window into the Problems of Small Manufacturers**

In addition to its intrinsic importance, the prevalence of small firms in the machine-tool industry makes it an ideal research vehicle for studying some of the more general problems facing U.S. small- and medium-sized establishments (SMEs). From this perspective, now is a particularly good time to reexamine the machine-tool industry, because the Clinton administration brings a new approach to the areas of technology and industrial policy and has singled out small manufacturers as a key element in its proposals for improving U.S. industrial competitiveness and generating new jobs (White House, 1993). Among the issues that are common to machine-tool makers and many other SMEs are access to capital, difficulties of exporting, and the adequacy of the skill base. Thus, analyzing the numerous federal and state initiatives that have been attempted in this area and their impact—or lack of impact—on the machine-tool industry may provide useful insights to help formulate new policy initiatives. Indeed, while the remit for this research was to investigate the U.S. machine-tool industry, both the problems facing this sector and their potential solutions appear to extend beyond the bounds of this particular industry.

There are, however, inherent limitations in an industry case study of this kind. Because our empirical work is confined to the machine-tool industry, we cannot say definitively whether these reforms will aid other sectors; that will await the conclusion of other industry studies, such as those in automobiles, semiconductors, steel, textiles, and financial services now being funded by the Sloan Foundation. Thus, this report should be seen as part of a growing body of industry case studies that, together, may suggest new directions for government policy.

**STRUCTURE OF THE REPORT**

This report is divided into seven chapters:

- In Chapter Two, we define the specific problems addressed in this study and describe our analytic approach.
- In Chapter Three, we investigate the decline of the industry in the early 1980s.
- In Chapter Four, we examine the major structural weaknesses that inhibited the U.S. machine-tool industry from responding to new competitive conditions.
- In Chapter Five, we analyze the recent recovery of the U.S. machine-tool industry, the different strategies that U.S. machine-tool companies are pursuing, and

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4Recent analysis of plant-level data indicates that the net job growth from small firms may be much smaller than some have claimed (Davis et al., 1993).
the technologies that are likely to have the greatest impact on this market in the future.

- In Chapter Six, we review existing U.S. and foreign government policies and suggest ways that the U.S. federal, state, and local governments could strengthen the U.S. machine-tool industry.

- Finally, in Chapter Seven, we present a summary of our main conclusions and policy options.

While these chapters constitute a self-contained document, we have also prepared a number of detailed appendices, which are contained in the second volume of this report. These contain a wealth of new information, including case studies of the three leading foreign machine-tool industries, an analysis of U.S. performance in key product market segments, and projections of key future machine-tool–related technologies.

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5All subsequent citations of appendices in this document refer to this companion volume (Finegold, ed., 1994), unless otherwise indicated.
At first glance, the main focus of this study—the declining competitiveness of the U.S. machine-tool industry—appears relatively straightforward. In actuality, however, what is meant by these terms—"competitiveness," "U.S.," and "machine-tool industry"—requires further explanation. The following sections define each term for the purposes of this study.

**COMPETITIVENESS**

Laura D'Andrea Tyson, chair of the President's Council of Economic Advisers, defines "competitiveness" as "the ability of a nation to produce goods and services that meet the test of international competition while providing sustained increases in the standard of living of its citizens" (Tyson, 1992). While economists debate the relevance of such concepts as national competitiveness,\(^1\) it is clear that, for particular industries, the ability of firms to compete successfully in global markets can be crucial. We measure the competitiveness of the U.S. machine-tool industry by analyzing the changing U.S. share of world and domestic markets for machine tools as a whole, the import-export ratios in particular market segments, and the relative productivity of U.S. machine-tool makers against their chief foreign rivals. It is important to examine these trends over a long period of time, since firms may boost their sales in the short term by selling tools at or below cost. To capture the contribution of the machine-tool industry to the "standard of living" of U.S. citizens, we analyze the shifts in employment and wages over time.

One problem with gauging U.S. machine-tool competitiveness in practice is the existence of tariff and nontariff barriers, including the Voluntary Restraint Agreements (VRAs) that the U.S. imposed on certain types of Japanese and Taiwanese machine tools from 1987 to 1993.\(^2\) This means that U.S. machine-tool makers did not face the full "test of international competition."

A separate but related issue is whether the U.S. government should be concerned with the competitiveness of particular industries. Neoclassical economists argue

\(^1\)For a critique of the concept of national competitiveness, see Krugman, 1994.

\(^2\)After the initial draft of this report was submitted to OSTP, the Clinton administration decided to allow the VRAs to expire at the end of 1993.
that each nation inevitably has sectors in which it enjoys comparative advantages and disadvantages and that the decline of a particular industry need not cause governmental concern. Strategic trade theorists counter that the main U.S. rivals are not playing according to neoclassical theory, but instead are increasing their national welfare at the expense of the United States, thanks to close cooperation between business and government at key developmental phases in targeted export industries. This broader debate on competitiveness is beyond the scope of this report. Instead, we have concentrated on understanding the important role that machine tools play in the wider economy, on the problems of the U.S. machine-tool industry, and on developing a policy options that could improve the performance of this sector. Because of similarities between the machine-tool industry and many other U.S. manufacturing sectors, these policies may, in fact, have much broader applications.

THE UNITED STATES

As the machine-tool industry, like virtually all manufacturing, becomes more global, it becomes more difficult to determine what firms qualify as American machine-tool makers. Is a company's country of origin the key criterion? Or the location of its manufacturing operations? Or the location of its high-value-added jobs? Under the procurement rules for the Department of Defense, for example, a U.S. tool must have at least 51 percent domestic content. A U.S.-owned firm can satisfy this requirement by purchasing a conventional tool body from Taiwan, adding a Japanese-designed controller made under license in the United States, and then selling it for more than twice the price it paid for the Taiwanese machine. Is this tool more or less American than one built almost from scratch in the United States by a Japanese-owned firm, with only a few key components originating in Japan? While machine-tool production is more vertically integrated than many manufacturing industries, the spread of modular manufacturing and global sourcing of some key components (particularly controllers) makes it even more difficult to determine the country of origin of a specific tool. This picture is further complicated by the creation of joint ventures—such as GE/FANUC in controllers—between multinational firms.

The basis for determining whether a machine-tool firm is counted as part of the U.S. machine-tool industry will depend to some extent on the type of data being analyzed. The figures on the world's largest machine-tool firms, for example, focus on country of origin/ownership, while the data on U.S. production and trade include shipments from foreign-owned plants that are based in the United States. Given the national security concerns and maker-user proximity advantages outlined in Chapter One, it seems sensible to define a U.S. machine-tool firm as one capable of developing and manufacturing a machine within the United States—e.g., one with an R&D

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3 The surge in machine-tool imports in the early 1980s, which precipitated the decline of the U.S. machine-tool industry, almost certainly benefited the U.S. economy as a whole, by giving U.S. manufacturers access to cheaper, more efficient tools; of course, if the United States had been able to successfully commercialize the computer numerical control (CNC) tools it developed, it might have avoided the decline and still helped U.S. manufacturers.
and engineering capability in its U.S. operations. This definition excludes "screwdriver" or strictly assembly plants, but includes some foreign-owned facilities.

MACHINE-TOOL INDUSTRY

Machine tools have historically been defined as machinery that cuts or forms metal and associated accessories (Standard Industrial Classification [SIC] codes 3541, 3542, 3545 and 3549).

Confining ourselves to traditional metal-cutting and -forming machines, however, would run the risk of the "buggy whip" problem—finding that the United States was competitive in a particular market only to discover that this market was soon to disappear. After decades of relative stasis, machine tools have experienced rapid technological change, transforming the basis of competitive advantage in the sector. Thus, we initially sought to broaden the traditional definition of machine tools to include

- those technologies which are of critical importance now (such as machine-tool controls)
- those that could replace some or all aspects of metal-cutting and -forming in the future (such as layered manufacturing, injection molding, micromanufacturing, laser cutting)
- those machines that manufacture structural parts from new materials (such as plastics or advanced ceramics).

It is important to note, however, that our ability to analyze machine tools defined this broadly was strongly limited by the way in which the U.S. government collects industry data; there is no separate SIC code category for plastic-cutting machines, for example, while there continue to be classifications for many conventional machines that are now technologically obsolete (see Appendix H on data problems).

Even under a more restricted definition of machine tools, there are many, very different product segments. It is crucial to distinguish between customized tools (such as the multimillion-dollar transfer lines developed to the precise specifications of large automakers), specialized tools (which perform a specific function or set of functions, but which may be produced in batches), and general-purpose commodity machines (such as machining centers, which can be made in large numbers and sold through a catalog, and which are capable of a wide variety of machining tasks). These machines may be sold individually or as part of systems, from a small manufacturing cell to a fully equipped factory. It is also important to separate CNC from conventional machines. Machine tools are classified both by functional category (e.g., lathe, punch press) and by type of control. Table 2.1 provides short descriptions of the major types of machine-tool controls.

Just as there are many types of machine tools, so too there is no single machine-tool industry, but rather many separate machine-tool businesses, each with different
Table 2.1
Types of Machine-Tool Control

<table>
<thead>
<tr>
<th>Manual control</th>
<th>These tools are controlled entirely by a human operator. Cutting and forming tools respond to the operator's hand movements of controls. Accuracy depends upon the operator viewing scales and gauges and by his observation of the machining operation itself.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numerical control (NC)</td>
<td>Numerical controls replace the human operator with automatic movement of cutting and forming tools. The automatic movements are typically determined by computer punch tapes. While some numerically controlled machines are capable of a wide variety of tasks, reprogramming the machine to perform a new task is difficult.</td>
</tr>
<tr>
<td>Computer numerical control (CNC)</td>
<td>Computer numerical controls, like numerical controls, automatically determine the movements of cutting and forming tools. CNC machines replace the tape reader with computer software. The computer can quickly be reprogrammed to allow the machine tool to perform a variety of tasks. Separate machines can be linked and programmed centrally through a computer network. In a few cases, controllers can now convert drawings from a computer-aided design (CAD) system directly into machine-tool instructions without the need for manual reprogramming.</td>
</tr>
</tbody>
</table>

characteristics and competitive requirements. As we will explore in more detail in Chapters Four and Five, the U.S. machine-tool industry is divided into a few large producers, which account for the majority of output and exports, and hundreds of small, family-owned firms. With the exception of a few diversified producers (e.g., Giddings & Lewis, Cincinnati Milacron), almost all firms tend to specialize in particular product segments (including specific components) and/or types of end user.

METHODOLOGY AND SOURCES OF INFORMATION

One sign of the importance attached to the machine-tool industry is the number of studies, both in the United States and abroad, that have focused on this sector in the last decade. These studies have tended to approach the machine-tool industry from a particular angle—e.g., national security (National Research Council, 1983), technology (Council on Competitiveness, 1991), or skills (Gordon and Krieger, 1993). The analysis presented here, in contrast, is designed to cover the full range of issues that affect the competitiveness of the U.S. machine-tool industry. To accomplish this, the Critical Technologies Institute project team included 19 people from four countries and a variety of disciplines: engineering, economics, political science, etc. The attempt to produce a holistic and comprehensive analysis has led to other unique study components:
• In-depth international comparisons, including case studies of the German, Italian, and Japanese machine-tool industries (see Appendices A–C).  

• Detailed review of existing technologies, along with projections of the future technologies that are likely to have an impact on this sector (Appendix F).  

• Analysis of a previously unexploited database on individual establishments, which covers substantially more plants than the official U.S. Census of Manufactures and several times as many as the industry’s trade association.  

Our data collection process started with a review of the extensive literature on the machine-tool industry. We used this to formulate a set of hypotheses that were then tested through economic analysis of the data available from government surveys (e.g., Current Population Survey, County Business Patterns), the four countries’ machine-tool industry associations, firm-level databases (Donnelly, Disclosure) and trade journals (American Machinist), and from more than 250 interviews (with machine-tool makers, suppliers, distributors, and users, as well as industry experts and policymakers). We also conducted detailed case studies of the changing competitive dynamics in key product technologies (CNC and transfer lines—see Appendices D and E) and of leading machine-tool firms in the United States and abroad. The latter included a comparison of the domestic and U.S. plants of a leading German and a leading Japanese machine-tool maker; this enabled us, for example, to see how these foreign firms operate and perform with a U.S. workforce.  

We also analyzed a wide array of state and federal policy initiatives that were intended to improve the performance of U.S. manufacturers and the machine-tool industry in particular. To get the reactions of industry to the different policies and the feasibility of implementing them, we conducted five focus groups with a total of 35 machine-tool experts across the United States (see Appendix G on focus groups). The industry experts were asked to rank each policy area based on two dimensions: its importance to the machine-tool industry and the capacity of the government to improve the situation.  

We analyzed both the quantitative and qualitative data to derive conclusions about the factors that are most significant in explaining the failure of the U.S. machine-tool industry to adapt to the new competitive context. We used this analysis to develop a set of policy options designed to address the decline of the machine-tool industry. Many of these actions are not exclusive to the machine-tool industry, but are rather intended to improve manufacturing processes in the United States and enable firms to compete more effectively in the global marketplace. We believe that such a broad

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4The Italian case is of particular interest, for while Italy’s machine tool industry is now roughly equal in size to that of the United States, it remains virtually unstudied in this country.  

5Unlike the census, this database, the Donnelly Businessline, identifies firms that operate in the machine-tool industry even if it is not their primary business.  

6The number of participants in the focus groups, while small, exceeded the sample size of many surveys that have been done of the machine-tool industry.
strategy, which encompasses the users as well as producers of machine tools, is likely to be the most effective way for the U.S. machine-tool industry to become more competitive.
To understand what actions might strengthen the U.S. machine-tool industry, we must first understand the reasons for the loss of competitiveness that the industry experienced during the 1980s. This chapter provides the essential details about that decline: how extensive it was, which parts of the industry suffered most, and what historical conditions seem to explain it. (Chapter Four, in contrast, analyzes the structural weaknesses that both contributed to the decline and explain the industry's failure to rebound when conditions changed.)

EXTENT OF THE DECLINE

The United States lost its long-held preeminence in the production of machine tools during the early 1980s. Through the 1970s, U.S. leadership in this market was supported by a large domestic demand for machine tools coupled with a steady flow of technological innovations developed for military needs.\(^1\) The United States pioneered the development of the technologies that revolutionized the machine tool industry: NC and CNC.

Yet in only a decade, the U.S. machine-tool industry fell from a position of leadership to that of a second-tier producer within a partially protected market. Germany and Japan have become the world's leading machine-tool producers (see Figure 3.1). The U.S. share of world markets dropped from 20 percent in 1980 to just over 7 percent a decade later, at the same level as Italy, whose economy is less than one quarter the size of the U.S. economy. The loss of U.S. machine-tool competitiveness was most evident in the domestic market, where imports surged from 24 to 54 percent of total U.S. sales in just seven years (see Figure 3.2).\(^2\) As a consequence, the historical U.S. trade surplus in machine tools evaporated, giving way to a trade deficit of $1.7 billion in 1986 (see Figure 3.3).

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\(^1\)The U.S. military had been pervasive in the development of modern machine tools. Servo technology, for instance, was originally developed for the Navy. Later, Air Force-sponsored research at MIT, coupled with such contractors as General Electric and Bendix, was key in the development of NC and CNC technologies.

\(^2\)The United States has since regained a small portion of its domestic market (imports accounted for 46.3 percent of sales in 1992) thanks in part to the introduction of VRAs. The trade deficit also narrowed, to $660 million in 1992.
With this drop in competitiveness, the size of the U.S. machine-tool industry was cut in half. Production in 1991 was just 42 percent of its 1980 level; total employment declined from 108,000 to 53,300 between 1980 and 1992, with the number of production workers dropping from 71,100 to 32,800 (see Figure 3.4). While all segments of the industry suffered, the decline was particularly sharp among small-sized firms; more than two-thirds of the 900 U.S. machine-tool establishments with fewer than 20 employees closed between 1982 and 1987 (U.S. Census, in Wieandt, 1992).

**PRODUCT MARKET BREAKDOWN**

Clearly, the U.S. industry’s overall decline in market share is dramatic. Yet these general trends mask important variations in performance in different product segments. The United States was hit most heavily by imports of standardized, relatively low-cost CNC tools; in some more expensive and sophisticated segments (transfer lines, for example), U.S. machine-tool makers retained a large share of the domestic market. Even in these tools, however, the U.S. became a net importer (see Appendix E). The majority of the production decline occurred in just one year: Between 1982 and 1983, production of U.S. metal-cutting machines declined by 53 percent; metal-forming production performed only slightly better, declining by 37 percent (see Figure 3.5). In subsequent years, production of metal-cutting machines has remained stagnant, while metal-forming production increased steadily but still did not recover to 1982 levels.
Figure 3.2—Share of U.S. Market: Domestic and Imports

Figure 3.3—U.S. Machine-Tool Trade Balance

Figure 3.4—Decline in U.S. Machine-Tool Employment

Figure 3.5—U.S. Production: Metal Cutting Versus Metal Forming

U.S. production of NC and CNC machine tools showed a similar pattern of stagnation over these years, despite large increases in U.S. and worldwide demands for these machines (see Figure 3.6). All told, the United States lost 18 percent of its market share for NC machines, with the most dramatic losses coming in the two most rapidly growing market segments: general-purpose CNC machining centers and lathes. CNC lathes alone accounted for half of Japan's imports to the United States prior to the introduction of VRAs.

The U.S. machine-tool industry's poor performance in most product categories during the last decade is clearly reflected in its declining share of domestic consumption. Table 3.1 demonstrates that the United States lost market share in most categories of machine tools in the mid-1980s, but recovered somewhat in some important products in the latter part of the decade. U.S. domestic market share fell by approximately 20 percent between 1982 and 1991 in the broad categories, metal cutting and metal forming, showing a steady decline through the decade. Only one category of U.S. products—punching and shearing machines—actually gained market share. All other tool types lost, some more than others. Among the worst-performing products were horizontal NC lathes and forging machines. In 1991, the United States held less than 40 percent of its own domestic market in each of these categories.

![Graph showing production levels of NC and Non-NC machines from 1982 to 1991.](image)

**Figure 3.6—U.S. Production: CNC Versus Non-CNC**

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³While overall U.S. demand was stagnant, demand for CNC, both stand-alone and integrated controls, grew from $1.25 billion in 1983 to $2.1 billion in 1991.
Table 3.1


<table>
<thead>
<tr>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>All machine tools</td>
<td>73.6</td>
<td>58.6</td>
<td>52.6</td>
<td>54.9</td>
<td>3,168.2</td>
</tr>
<tr>
<td>Metal cutting</td>
<td>72.6</td>
<td>56.7</td>
<td>48.5</td>
<td>53.8</td>
<td>2,135.2</td>
</tr>
<tr>
<td>Metal forming</td>
<td>77.5</td>
<td>64.2</td>
<td>61.4</td>
<td>57.0</td>
<td>1,033.0</td>
</tr>
<tr>
<td>All NC machines</td>
<td>64.6</td>
<td>45.5</td>
<td>48.0</td>
<td>46.5</td>
<td>1,233.4</td>
</tr>
<tr>
<td>Boring and drilling</td>
<td>73.1</td>
<td>55.5</td>
<td>55.4</td>
<td>49.8</td>
<td>115.0</td>
</tr>
<tr>
<td>Gear cutting</td>
<td>71.9</td>
<td>60.5</td>
<td>25.6</td>
<td>51.1</td>
<td>115.2</td>
</tr>
<tr>
<td>Grinding</td>
<td>77.4</td>
<td>70.2</td>
<td>52.9</td>
<td>60.6</td>
<td>378.9</td>
</tr>
<tr>
<td>Horizontal NC lathes</td>
<td>51.8</td>
<td>42.9</td>
<td>34.9</td>
<td>39.8</td>
<td>206.3</td>
</tr>
<tr>
<td>Vertical NC lathes</td>
<td>72.3</td>
<td>48.0</td>
<td>59.5</td>
<td>66.0</td>
<td>63.1</td>
</tr>
<tr>
<td>Non-NC lathes</td>
<td>48.9</td>
<td>39.2</td>
<td>13.6</td>
<td>42.4</td>
<td>47.7</td>
</tr>
<tr>
<td>Milling</td>
<td>73.4</td>
<td>54.6</td>
<td>60.1</td>
<td>71.6</td>
<td>201.1</td>
</tr>
<tr>
<td>Machining centers</td>
<td>63.1</td>
<td>37.0</td>
<td>48.2</td>
<td>50.6</td>
<td>361.8</td>
</tr>
<tr>
<td>Station type</td>
<td>96.9</td>
<td>95.1</td>
<td>75.8</td>
<td>64.8</td>
<td>450.4</td>
</tr>
<tr>
<td>Other metal cutting</td>
<td>65.0</td>
<td>45.1</td>
<td>36.1</td>
<td>25.7</td>
<td>195.7</td>
</tr>
<tr>
<td>Punching and shearing</td>
<td>65.4</td>
<td>60.0</td>
<td>68.0</td>
<td>69.2</td>
<td>180.8</td>
</tr>
<tr>
<td>Bending and framing</td>
<td>79.3</td>
<td>64.8</td>
<td>54.3</td>
<td>58.1</td>
<td>204.3</td>
</tr>
<tr>
<td>Presses</td>
<td>87.6</td>
<td>71.5</td>
<td>58.8</td>
<td>59.6</td>
<td>297.9</td>
</tr>
<tr>
<td>Forging</td>
<td>74.8</td>
<td>66.9</td>
<td>51.2</td>
<td>24.3</td>
<td>42.1</td>
</tr>
<tr>
<td>Other metal forming</td>
<td>64.6</td>
<td>57.7</td>
<td>68.3</td>
<td>53.4</td>
<td>308.1</td>
</tr>
</tbody>
</table>

SOURCE: AMT.

NOTE: Categories covered by VRAs are in bold.

Despite the consistent loss of market share across categories, several U.S. products maintained a relatively strong position in their home market. In some cases, like transfer presses, the products are typically customized, making them difficult for firms to export to the United States. For a few products, like gear-cutting and punching-and-shearing machines, U.S. firms maintain a strong competitive position, because Japanese and other machine-tool makers have not been able to meet customer needs with commodity tools. In many key product markets, however, the United States only maintained its market share by protecting its domestic market. The VRAs covered seven categories of Japanese and Taiwanese machine tools, including the large markets for milling machines, CNC lathes, and machining centers. The VRAs for each category were set at 1981 import levels, enabling U.S. firms to recover some of the market share they lost in the early 1980s.

Competitive advantage is most directly reflected in product performance in international markets. A good measure of international performance in a given market segment is the net export ratio (Taymaz, 1989). A positive value of the net export

\[ \text{Net Export Ratio} = \frac{E - I}{E + I} \]
ratio represents trade surplus in the product category, and strong international performance. A negative net export ratio indicates a negative trade balance and poor international performance. As Table 3.2 indicates, while the U.S. industry faces a trade deficit for most machine-tool products, U.S. producers managed to maintain or improve their international performance in several unprotected segments, most notably bending-and-framing, gear-cutting, and forging machines. In some specialized markets, such as large five-axis machining centers, the U.S. maintains a dominant position in world markets. The total world demand for these expensive machines, however, is limited and shrinking, as the capabilities of much-lower-cost, standardized machines improve.

Despite large declines in production and a significant trade deficit, U.S. exports of machine tools actually increased in absolute terms between 1982 and 1992. After a sharp decline between 1982 and 1983 (exports dropped 40.42 percent in one year), many U.S. firms were able to gain back the loss in export sales. U.S. exports of forging machines and gear-cutting machines saw the strongest growth among the major categories, with NC machines, machining centers, bending-and-framing machines

| Table 3.2 |
| Net Export Ratios for Machine-Tool Market Segments |

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>All machine tools</td>
<td>-0.35</td>
<td>-0.61</td>
<td>-0.48</td>
<td>-0.39</td>
</tr>
<tr>
<td>Metal cutting</td>
<td>-0.45</td>
<td>-0.68</td>
<td>-0.59</td>
<td>-0.51</td>
</tr>
<tr>
<td>Metal forming</td>
<td>0.02</td>
<td>-0.38</td>
<td>-0.24</td>
<td>-0.07</td>
</tr>
<tr>
<td>All NC machines</td>
<td>-0.62</td>
<td>-0.79</td>
<td>-0.70</td>
<td>-0.57</td>
</tr>
<tr>
<td>Boring and drilling</td>
<td>-0.45</td>
<td>-0.49</td>
<td>-0.48</td>
<td>-0.43</td>
</tr>
<tr>
<td>Gear cutting</td>
<td>-0.11</td>
<td>0.00</td>
<td>-0.10</td>
<td>0.17</td>
</tr>
<tr>
<td>Grinding</td>
<td>-0.25</td>
<td>-0.45</td>
<td>-0.21</td>
<td>-0.38</td>
</tr>
<tr>
<td>Horizontal NC lathes</td>
<td>-0.73</td>
<td>-0.88</td>
<td>-0.81</td>
<td>-0.75</td>
</tr>
<tr>
<td>Vertical NC lathes</td>
<td>-0.73</td>
<td>-0.34</td>
<td>-0.83</td>
<td>-0.85</td>
</tr>
<tr>
<td>Non-NC lathes</td>
<td>-0.45</td>
<td>-0.55</td>
<td>-0.35</td>
<td>-0.67</td>
</tr>
<tr>
<td>Milling</td>
<td>-0.59</td>
<td>-0.75</td>
<td>-0.57</td>
<td>-0.35</td>
</tr>
<tr>
<td>Machining centers</td>
<td>-0.69</td>
<td>-0.88</td>
<td>-0.83</td>
<td>-0.68</td>
</tr>
<tr>
<td>Station type</td>
<td>0.66</td>
<td>-0.65</td>
<td>-0.66</td>
<td>-0.64</td>
</tr>
<tr>
<td>Other metal cutting</td>
<td>-0.19</td>
<td>-0.68</td>
<td>-0.67</td>
<td>-0.30</td>
</tr>
<tr>
<td>Punching and shearing</td>
<td>-0.25</td>
<td>-0.63</td>
<td>-0.05</td>
<td>-0.03</td>
</tr>
<tr>
<td>Bending and forming</td>
<td>0.05</td>
<td>-0.42</td>
<td>-0.43</td>
<td>-0.09</td>
</tr>
<tr>
<td>Presses</td>
<td>0.14</td>
<td>-0.33</td>
<td>-0.35</td>
<td>-0.24</td>
</tr>
<tr>
<td>Forging</td>
<td>-0.17</td>
<td>0.03</td>
<td>0.06</td>
<td>-0.02</td>
</tr>
<tr>
<td>Other metal forming</td>
<td>0.19</td>
<td>-0.31</td>
<td>-0.11</td>
<td>0.05</td>
</tr>
</tbody>
</table>

SOURCE: AMT.
NOTE: Categories covered by VRAs in bold.

have a value between -1 and 1. An export-import ratio at or near zero indicates that export and imports are relatively equal.
and metal-forming presses following closely. U.S. lathes and boring-and-drilling machines performed most poorly on international markets during the 1980s.

It should be noted that increases in U.S. machine-tool exports during this period, while certainly beneficial to the industry, did not come close to offsetting industry losses due to the decline in domestic sales. U.S. exports in 1981 accounted for less than 10 percent of sales. Given this small base, subsequent growth in exports was not enough to create significant changes in industry trends. The United States has become more export-oriented during the 1980s, but absolute levels of exports remain small in relation to other leading machine-tool producers, and have not kept pace with the growth in world demand (see Chapter Four).

CAUSES OF THE DECLINE

What accounts for the major decline of the U.S. machine-tool industry in most product segments? We divide the answer to this question in two parts: This chapter focuses on a set of historical conditions that can explain the U.S. industry’s decline in the early 1980s; Chapter Four analyzes the structural weaknesses in the U.S. machine-tool industry relative to its main competitors that not only contributed to this decline but also help explain the failure of U.S. machine-tool manufacturers to rebound under the new competitive conditions.

Four historical factors stand out as credible explanations of the decline of the U.S. machine-tool industry in the early 1980s. First, the U.S. machine-tool industry has always been heavily dependent on U.S. consumption of machine tools. This domestic demand dropped precipitously in the early 1980s and has remained stagnant since then. Second, the strategy that U.S. companies used to cope with the highly cyclical nature of machine-tool demand backfired. Third, U.S. machine-tool productivity fell in real terms while competitors, in particular the Japanese, made dramatic improvements in efficiency through the redesign of both processes and products. And fourth, the value of the dollar was very high in real terms during the early to mid-1980s, hurting the price competitiveness of the U.S. industry both at home and in export markets. In the remainder of this chapter, we explore each factor in some detail.

Declining Domestic Market

For U.S. manufacturers in general, the large size of the U.S. economy is both a blessing and a curse. Because of the opportunities available within the United States, many U.S. manufacturers have focused their sales strategies almost entirely on the domestic market. This was particularly true of small- and medium-sized manufacturing firms—the sort of firms that build machine tools. Many machine-tool makers depended on a thriving domestic market for their survival. That market collapsed in the early 1980s and never recovered. Between 1980 and 1990, U.S. consumption of machine-tools fell 37 percent in real terms. By contrast, demand in the rest of the world for machine tools was growing rapidly, with machine-tool purchases in the Pacific Rim expanding by 104 percent and Western Europe by 55 percent during the
same period (see Figure 3.7 on shifts in global consumption). By 1990, German and Japanese machine-tool markets were both more than double the size of the U.S. market.\(^5\)

**Growing International Competition**

U.S. machine-tool makers continued to act as though they were part of a closed economy long after the industry had globalized. Prior to the large decline in the early 1980s, the machine-tool industry was notoriously volatile. The response of U.S. machine-tool makers was typically to build up a backlog of orders during booms, then work off those orders during economic downturns. This strategy avoided the problem of creating excess capacity. Entering the 1980s, the U.S. machine-tool industry as a whole had accumulated order backlogs greater than total annual production (see Figure 3.8). While this strategy stabilized the work load of machine-tool makers, the customers of some of the most successful U.S. machine-tool firms had to wait from two to four years for the delivery of the tools they ordered (Holland, 1989).\(^6\) Yet, even though this backlog strategy alienated many customers, it was sustainable so long as two conditions held: (1) Few alternative sources of supply were available;\(^7\) and (2) the technology was relatively stable. These conditions

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\(^{5}\)Both the Japanese and German markets have declined sharply in the last several years, though they each remain twice the size of the U.S. market; precise figures for 1992–1993 are not yet available.

\(^{6}\)The backlog strategy was even more disastrous for U.S. machine-tool makers in Europe than at home, conceded a former senior executive in a large U.S. firm; European orders were put at the bottom of the queue, causing many long-time users to take their business elsewhere (RAND Interviews).

\(^{7}\)The major U.S. machine-tool firms tended to specialize in certain types of products. As far back as the 1920s, the large U.S. machine–tool firms had informal agreements to stay out of each other’s key market niches (Herrigel, 1993a; RAND interviews).
ceased to apply in the early 1980s. When demand for machine tools began to pick up, spurred by the defense buildup and the retooling of U.S. automakers, the Japanese were able to make dramatic gains in market share by delivering new, reliable CNC tools within weeks (see Figure 3.2).\(^8\) To make matters worse, they could sell these tools at a price that U.S. machine-tool makers could not match, thanks to large cost advantages and generous export finance (described in Chapter Four). Once the Japanese gained a foothold in the U.S. market, they were able to expand by offering generous deals to the best U.S. distributors to sell their machines exclusively (RAND interviews).

**Japan's Productivity Advantage**

Productivity in the U.S. machine-tool industry remained stagnant or declined through much of the 1980s, at a time when the U.S. manufacturing sector showed slow but steady improvements in productivity (see Figure 3.9). Efforts to measure

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\(^8\)The Japanese adopted a different approach to the problem of excess capacity, subcontracting out a higher percentage of production to keep fixed costs low and building some machines for stock when demand was slack.
and explain productivity are fraught with methodological difficulties, but even rough calculations show that U.S. machine-tool makers failed to increase real value per worker since the 1950s (Alexander, 1990). U.S. machine-tool makers were slow to reengineer their production processes and to replace their old machines with new CNC equipment, which offered large potential gains in setup and machining times.

Measuring productivity is always a problem, and making sensible comparisons internationally is even more difficult. In this analysis, we examine one imperfect indicator: labor productivity. Most manufacturing processes can be accomplished using a variety of methods and a variety of factor inputs. Normally, labor and capital are substitutes. By heavily investing in plant and equipment, a firm or nation can boost its labor productivity greatly, but it may increase rather than decrease its costs if it invests too heavily. Similarly, a firm can hire only extremely skilled workers and again boost productivity per worker, but this also may not be a cost-competitive strategy.

Ideally, productivity should be measured by constructing a production function that includes all factor inputs. Once the factors are taken into account, remaining differences can be attributed to total factor productivity. Such an approach, however, is not possible with the available data on machine tools.

Furthermore, machine tools are an evolving and heterogeneous category, so aggregate measures can be misleading. Severe methodological problems arise in controlling for output quality across countries or over time (i.e., a CNC tool sold in the United States for $50,000 in 1994 is many times more productive than a similarly priced tool [in real terms] from 1964, but these changes in capacity are not reflected in the output per worker). Data availability and differences in outsourcing policies across nations also confound useful comparisons.

Finally, in making international comparisons, real exchange rate changes can greatly affect productivity comparisons. To be sure, data can be adjusted for such changes, but it is generally impossible to correct for both base-year comparisons and growth rates.

In spite of all these problems, productivity is a real and important concept. Measures of labor productivity presented here are designed to shed some light on what happened in the industry during the 1980s rather than to measure differences in productivity levels and growth rates definitively.
They also failed to make needed accompanying investments in workers' skills and new product development.

Japan: New Product and Process Technology

In Japan, by contrast, the combination of major product and process innovations created new markets and led to major gains in productivity.

**First-Mover Advantage in Controls.** The new product technology—a cheap, reliable CNC—enabled users to reprogram machines for various functions far more rapidly than was possible with numerical control.\(^{10}\) Ironically, a major technological factor in the success of the Japanese machine-tool industry here may have been the relative weakness of the Japanese computer industry in the 1970s. Whereas the United States, and to a lesser extent Europe, had a number of diversified computer makers and machine-tool makers themselves vying for the controller marketplace, in Japan a single firm—FANUC—emerged as the dominant manufacturer of controls.\(^{11}\) While the Western firms, each with its own proprietary standard, saw machine-tool controls as a relatively small product market relative to their other computer operations, FANUC concentrated on the machine-tool industry.\(^{12}\) Using servomotor technology licensed from the United States, it developed the first microprocessor-based control that was more flexible and, at least initially, cheaper than any controller on the market. FANUC's controls became the *de facto* world standard, with an estimated 70 percent of the global market, providing Japanese machine-tool makers with a substantial first-mover advantage. As machine-tool users began to fill their factories with CNC machines, they preferred to stay with the same controller for ease of programming, training, and maintenance. By 1988, the United States, which had invented CNC, was importing more than half of all its controls (both stand-alone and integrated), from Japan. (see Appendix D for a more detailed case study of controllers).

**Modularization Leads to Productivity Edge.** The new process technology—modularization—made possible much larger production runs of various machine-tool components than with batch or customized manufacturing processes. By designing their tools for ease of production and commonality of parts across machines, Japanese machine-tool makers were able to achieve greater economies of scale, while still producing an array of tools that covered most of the specialized

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\(^{10}\) U.S. firms were first in the market with CNC controls; what was new about FANUC's control was its reliability and low cost.

\(^{11}\) There is a dispute over what role, if any, the Ministry of International Trade and Industry (MITI) played in discouraging other Japanese firms from competing with FANUC (Friedman, 1988; Dertouzos et al., 1989). Several of the large Japanese machine-tool makers (Mazak, Okuma) developed their own controls because they did not want to be dependent on FANUC.

\(^{12}\) The leading U.S. control maker, General Electric (GE), concentrated too heavily on its internal corporate needs, neglecting the wider market. When GE finally responded to FANUC's challenge in the early 1980s, it rushed products to market and damaged its reputation just when demand was increasing (Vogel, 1985).
functions which customers desired. In the leading Japanese firms, modularization cut the number of separate parts and tools by up to 90 percent (McKinsey Global Institute, 1993). This, in turn, made CNC tools affordable to even the smallest job shop, creating a new market. The standardization of the production process also enabled Japanese machine-tool makers to improve the reliability of individual machines, an increasingly important factor in machine-tool purchasing decisions.

Perhaps the major advantage Japan gained from modularization was that modularization transformed the production of machine tools from a craft industry to the type of industry in which Japan is a world leader: large-scale manufacturing where cost and quality are crucial. This transformation of the production process gave the Japanese a large productivity lead over their main rivals. A recent study by the McKinsey Global Institute (1993) found that Japanese machine-tool firms were able to produce 35 percent more added value per employee than their U.S. and German rivals. Even more striking differences were found in a German-Japanese comparison, which calculated that the value added per production worker in large Japanese companies was double that of their German rivals throughout the 1980s (see Figure 3.10). The productivity advantage was most notable in standardized CNC tools, which account for the vast majority of Japanese exports.

In addition to the advantages conveyed by modular production and accompanying economies of scale, Japan's productivity and cost lead was also the result of

- greater reliance on subcontracting (53 percent of output versus 41 percent in the United States and Germany)
- more hours worked (2,197 per year in Japan in 1990, versus 1,963 in the United States and 1,604 in Germany)
- greater investment in its own CNC tools that reduced set-up and running times, decreased inventories, and increased flexibility
- a highly skilled workforce that could respond rapidly to changing technologies and contribute to continuous innovation.

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13 The president of Mazak's parent, Yamazaki, for example, had his engineers dismantle three different tools and then questioned them to discover if similar parts could be made identical. For a more detailed description of the introduction of modular machine tools, see Appendix A and Alexander (1990).

14 It is important to make a distinction between reliability and low maintenance, on the one hand, and quality or sophistication on the other. According to a major purchaser of machine tools at one of the Big Three U.S. automakers, U.S. tools are often as sophisticated as their Japanese counterparts, but do not score as well on reliability. This factor increases in importance as machines on the shop floor become more integrated in a just-in-time production system, thereby multiplying the costs of downtime for any one machine (RAND focus group).

15 See Appendix B, Tables B.10 and B.11. U.S. firms were not included in this sample, but as Figure 3.7 suggests, U.S. firms trailed those of Germany and were far behind Japan's throughout this period.

16 For example, Okuma, one of Japan's leading machine-tool makers, turns its inventory around an average of 20 times per year, compared to five or six times for the top-performing U.S. machine-tool makers (RAND focus group).
Figure 3.10—Labor Productivity in the Japanese and German Machine-Tool Industries

**Behind the Japanese Advantage.** While a large part of Japanese industry’s success can be attributed to farsighted managers who placed a special emphasis on continuous improvements in the manufacturing process, they were aided in this strategy by a set of peculiar historical circumstances (for a fuller discussion of the Japanese case, see Appendix A). Japanese machine-tool makers benefited from the surge in the demand for machine tools in their home market, which grew from less than $2 billion to more than $7 billion between 1975 and 1991.\(^{17}\) The investment boom and the competition it spawned kept constant pressure on machine-tool makers to come up with new improvements in flexible manufacturing technology. The government intensified this pressure by passing a law which stipulated that half of all machine tools produced should be CNC by 1977.\(^{18}\) This pressure for innovation was reinforced by the rapid turnaround time of the large machine-tool investors, who typically expect to use a machine for as little as five years before purchasing a more sophisticated model (RAND interviews). There was also a huge demand for these new and relatively inexpensive tools among the tiers of small Japanese metalworking subcontractors, who were able to use the reprogrammable capacity of CNC to switch easily from one order to another (Friedman, 1988). This early investment in CNC tools meant

\(^{17}\) Roughly half of this increase can be explained by the appreciation of the yen against the dollar. It was also during this period that Japan replaced the machines it had purchased following World War II (Schmidt, 1988).

\(^{18}\) MITI implemented the Extraordinary Measures Law for the Promotion of Specific Electronic and Machinery Industries by setting quality and performance standards for new machines (Vogel, 1985).
that when U.S. machine-tool users began to appreciate the benefits of the new flexible technology in the early 1980s, the Japanese already had a well-tested CNC product line to sell and the capacity to manufacture it on a large scale. The benefits of the large and sophisticated Japanese market were conveyed almost exclusively to Japanese machine-tool makers because of the relatively closed nature of this market (see Chapter Four, Trade section).

At the time when major investments were required in the new CNC technology, Japanese manufacturers also benefited from historically low costs of capital.\(^{19}\) This not only fueled domestic demand for machine tools and allowed machine-tool makers to invest heavily in their own CNC machines to improve productivity and flexibility, but also enabled machine-tool makers by building inventories of some tools and offering generous export financing to expand their shares of foreign markets.\(^{20}\)

**Germany: A Skills and Investment Strategy**

Like the United States, the German machine-tool industry was caught by surprise by the Japanese innovations in standardized CNC tools in the early 1980s. Unlike U.S. firms, however, German machine-tool makers, with significant government support, responded relatively quickly to this challenge. They were able to achieve major productivity gains by focusing on quality and by making a steady stream of investment in new equipment, training, and research and development. Also unlike the United States, Germany’s recovery was greatly facilitated by the expansion of its main market: Europe. The results of this strategy are shown in Figure 3.11 (for more details, see Appendix B).\(^{21}\)

**Exchange Rates**

If a collapse in the domestic market, a failed backlog strategy, and major advances abroad were not enough of a problem for the U.S. machine-tool industry, the high value of the dollar during the first half of the 1980s further reduced the industry’s competitiveness. Figure 3.12 shows the real trade-weighted exchange rate, as well as

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\(^{19}\) It is widely known that Japanese blue-chip firms were able to sell convertible bond issues at a premium during parts of the 1980s investment boom. Buyers were willing to pay the premium, because they expected to be able to convert the bonds to stock at a price well above par. Through such sales, firms were actually able to generate capital at negative costs.

\(^{20}\) Some caution needs to be used in making comparisons of capital costs across nations in nominal terms. Nations with high inflation rates tend to have high nominal interest rates, and vice versa. Similarly, nations whose currencies are expected to depreciate in nominal terms (which significantly overlaps those nations with high inflation rates) also tend to have high inflation rates. There is usually much more variation in nominal interest rates than in real interest rates expressed in a common currency. Even though Japan did have a policy of making cheap capital available to its manufacturing firms, most of these firms would have been better off borrowing in dollars from "expensive" U.S. sources and repaying the loans in appreciated yen.

\(^{21}\) Approximately 20 percent of Germany’s productivity improvement relative to the United States can be explained by the appreciation of the deutschmark versus the dollar, which improves measures of output per worker.
Figure 3.11—Labor Productivity in the U.S. and German Machine-Tool Industries

Figure 3.12—Real Exchange Rate and Machine-Tool Industry Performance

the performance of the machine-tool industry. The appreciating dollar during this period further widened the cost gap between the United States and Japan, undermined U.S. exports, and made imports cheaper.

Yet, the real exchange rate began to fall sharply in the latter half of the 1980s, and U.S. machine-tool manufacturers were not able to take advantage of the weak dollar to improve their competitive position. The question then becomes: Why did the U.S. industry fail to rebound? Chapter Four addresses this issue.
The introduction of CNC in the 1970s and its widespread adoption in the 1980s and 1990s has brought about dramatic shifts in the global market for machine tools. As Chapter Three illustrated, Japanese companies have been the most successful in adapting to this new competitive context, while U.S. machine-tool makers have suffered a major decline. This chapter will probe beneath the changes in market share to explore how the underlying basis for competitive advantage in machine tools has altered. After identifying the new requirements for success in machine tools, we will analyze the structural weaknesses that caused the U.S. machine-tool industry to fall behind its main competitors and that have prevented any significant recovery.

THE NEW COMPETITIVE CONTEXT

Fundamental changes in the machine-tool industry and its environment have created a new set of requirements for success. Seven characteristics seem most important:

- Rapid changes in product life cycle
- The blending of mechanical and electronic technologies
- The growing importance of system integration
- An increase in global integration and competition
- New skill requirements
- New capital requirements
- The increased importance of external relationships.

The following paragraphs briefly describe each characteristic.

**Rapid Changes in the Product Life Cycle**

For more than a century, the basic technology of metal cutting and metal forming remained relatively stable.¹ New products tended to come from the incremental in-

¹One of the machine-tool firms RAND visited was proud of the fact that it had, until recently, still used a machine that was built before 1900.
novations of skilled machinists, rather than labs of engineers with large research and development (R&D) budgets. Firms would often sell the same basic line of tools for 20 years, and the process of designing a new product range took several years. This situation changed dramatically as the punched tapes of NC were replaced by far more flexible CNC. Now, companies not only have greater need for incremental improvement, they are also being forced to substantially redesign products every five years or less to keep pace with advances in microelectronics and sensing devices. The redesign process is measured in months rather than years.

**Combining Mechanical and Electronic Technologies**

The Japanese have coined a new word that roughly translates to “mechatronics,” which sums up the major change that has taken place in machine-tool technology: new innovations in machine tools now combine the mechanics of cutting and forming metal with the software and hardware (electronics, sensors) that control this process. The development of machines capable of handling new materials (plastics, advanced ceramics, composites) is also gradually decreasing the importance of metal in advanced manufacturing (see Appendix F).

**Growing Importance of System Integration**

With the spread of CNC technology, there has been an accompanying shift in emphasis from stand-alone machines to integrated manufacturing systems. These systems can range from a small machining cell, in which two or more CNC machines are joined by an automated transfer mechanism, to an entire computer-integrated factory. This has given an edge to those machine-tool vendors who can offer the greatest compatibility and reliability in their machines, as well as assistance with system integration.

**Increased Global Integration and Competition**

There has historically been substantial international trade in machine tools. What has altered in the new global environment is the number and type of competitors, who have broadened from the United States and Europe to include a major new power, Japan, the newly industrialized countries (NICs), such as Taiwan, Spain, Korea, and in the near future, mainland China. NICs produce not only low-priced, conventional tools, but also increasingly more sophisticated CNC products with the aid of technology licensed from Japan. The other aspect of the greater global integration of the machine-tool industry is the increase in international joint ventures and outsourcing of components from other countries, as firms search for new markets and the most cost-effective production location.

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2 For example, a lathe designed in the mid-1970s could be expected to last eight years; by the mid-1980s, a new design was obsolete in three years (see Appendix C).

3 Unlike U.S. machine-tool makers in the 1950s, Japanese firms are careful to license only technology which is at least a generation out of date.
New Skill Requirements

To exploit the full potential of CNC, the workers who operate these new machines need a wide array of new skills (increased math and literacy, computer programming, electronic maintenance, statistical process control), while continuing to require an understanding of the mechanical fundamentals and craft of shaping metal (Scribner, 1991; Gordon and Krieger, 1993). These new skill demands are as pressing on machine-tool customers as on the makers themselves; indeed, the new environment is placing greater demands on machine-tool firms to offer users a full training package with any machine they sell (RAND interviews; Herrigel, 1993).

New Capital Requirements

Just as the customers of machine-tool firms can greatly enhance productivity through investments in new CNC machines, so can machine-tool makers. Indeed, there are two reasons why it may be more important for machine-tool firms to make this investment in the latest capital equipment: First, it gives them an opportunity to test and refine their own innovations and/or compare their machines with their main competitors; and second, because their production runs are typically short, the capacity for rapid reprogramming in the new CNC machines may be particularly important.

Greater Importance of External Relationships

The common thread that unites the different characteristics of the new machine-tool competitive environment is the need for new investments and building new capabilities (e.g., higher-level skills, diffusion of the latest technologies, export marketing, and product and process R&D). Those institutional systems that are able to share the costs and risks associated with these investments will have a distinct advantage in global markets. These forms of cooperation often take place among networks of firms with the help of external actors, such as employer organizations or the government (at the local, regional, or national level).

DETERMINANTS OF COMPETITIVE ADVANTAGE IN MACHINE TOOLS

We will now turn our attention to why the U.S. machine-tool industry has been less prepared to cope with this new set of competitive demands than its main rivals. This can be analyzed using a modified version of the framework that Michael Porter (1990) developed to analyze the competitive advantage of nations in different businesses (see Figure 4.1). Industry structure and the relations among firms are placed at the center of the diagram, because it is the companies themselves that will ultimately determine the success or failure of the industry. Factor inputs (technologies, skills, and capital) are essential ingredients if the industry is to stay innovative.4 The

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4Note that the arrows between skills and technology and industry structure are two-way, because these inputs will both be supplied by companies themselves and be brought in from outside.
government plays an overarching, potentially crucial role in this framework; it can help determine industrial competitiveness both through direct relations with industry and through its actions that affect supply and demand for machine tools. On the right side of the diagram are the market-related factors that shape demand, including both the nature of domestic consumption and the capacity of firms to export.

In the remainder of this chapter, our analysis proceeds systematically through each of the components of the illustrated framework, analyzing the link between these factors and the machine-tool industry's decline and failure to rebound.

**INDUSTRY STRUCTURE AND RELATED INDUSTRIES**

For small firms operating in isolation, the array of new capacities and investments required for success in the current machine-tool marketplace is difficult to attain. There are two ways to overcome this difficulty: (1) develop a critical mass of large machine-tool makers, or (2) establish cooperative networks among SMEs. The U.S. machine-tool industry, however, no longer has either of these features. Entering the 1980s, the United States was home to the world's ten largest machine-tool makers, which dominated the industry, accounting for over 15 percent of world output (*American Machinist*, various issues). By 1990, however, the United States had only one of the world's top ten producers. As Figure 4.2 demonstrates, Japan now has nearly half of the world's 60 largest machine-tool makers, and Germany has one-third, while the United States has only 8 percent.

Although these large companies are a small percentage of the total number of firms in the machine-tool industry, they account for a major share of total machine-tool production (see Figure 4.3). Japan and the United States have the most concentrated machine-tool industries, with the top five U.S. firms accounting for nearly half of all
Figure 4.2—Home Countries of World's 60 Largest Machine-Tool Firms, 1991

Figure 4.3—Percentage of National Machine-Tool Production of Top Firms, 1991

U.S. machine-tool sales in 1991, and the top 15 accounting for close to 70 percent.\textsuperscript{5} The U.S. machine-tool industry has become substantially more concentrated since World War II as a result of mergers and acquisitions, with an average of eight mergers per year from 1944 to 1958, rising to 13.5 per year between 1958 and 1968 (Research Management Corporation, 1969).\textsuperscript{6} While most of the earlier transactions involved consolidation among machine-tool makers, many of the acquisitions in the 1960s and 1970s involved large conglomerates (Bendix, Textron, Houdaille) taking over machine-tool firms. These transactions often proved disastrous for the machine-tool makers, because the financial managers of these diversified corporations were unfamiliar with the particular requirements and highly cyclical nature of the machine-tool industry (Holland, 1989; RAND interviews). When profits plummeted in the recessions following the 1973 and 1980 oil shocks, the conglomerates sold off their machine-tool acquisitions rather than put in the investments required to develop a new CNC product line and upgrade production equipment (RAND interviews; Herrigel, 1993a). This stands in stark contrast to Japan, where the dominant machine-tool makers have grown through internal expansion rather than acquisitions. Some of the leading Japanese machine-tool makers are part of keiretsu: horizontally and vertically integrated alliances of companies and banks. The keiretsu provide long-term financial support, export networks, and cooperative links for new product development between machine-tool makers and users.

There are several potential advantages to a firm being large in the machine-tool industry.\textsuperscript{7} The first derives from economies of scale in production. For example, the leading Japanese machine-tool makers produce 1,700 machining centers annually, compared with a maximum of 500 in the largest non-Japanese firm (Ehrnberg and Jacobsson, 1993).\textsuperscript{8} Another benefit from greater size stems from the ability of large companies to master the different technologies required to develop new products and then to market and service these products effectively on a global scale. This global reach is particularly important in machine tools because of the highly cyclical nature of the industry, as it enables firms to weather a recession in their home markets by selling abroad.\textsuperscript{9}

\textsuperscript{5}The concentration of the U.S. machine-tool industry would be even greater if these figures took into account the U.S. production of foreign-owned machine-tool firms, which accounted for at least three of the top ten machine-tool producers in 1991.

\textsuperscript{6}In 1947, the top 16 U.S. machine-tool makers accounted for 43.2 percent of industry shipments (Wagoner, 1968, p. 27), while in 1957, the leading 40 U.S. machine-tool makers accounted for 70 percent of output (Brown, 1957).

\textsuperscript{7}Large size provides no guarantee of success, as the British and French experience clearly demonstrates. In the 1970s, these governments intervened in their declining machine tool industries by encouraging mergers to create "national champions"; in neither case has this form of industrial policy been successful (Rendeloo, 1985; Scilberas and Payne, 1985).

\textsuperscript{8}The length of production runs in machine tools, however, is still relatively short by the standards of most manufacturing; indeed, the development of CNC tools has reduced the returns to scale by significantly cutting the time and costs required to switch between the parts being machined. In Germany, for example, 88 percent of all machine tool production is either custom or small batch (see Appendix B).

\textsuperscript{9}The most recent recession has been somewhat of an exception, hitting all three of the main machine-tool markets at the same time. Still, however, such companies as the German leader Trumpf have been able to offset their losses in Europe through sales in the rapidly growing Pacific Rim (Japan excepted) and a booming business for laser cutting machines in the United States.
A different way of achieving equally effective technological capacities is for networks of small companies to pool resources. In the three leading machine-tool exporting countries, small- and medium-sized machine-tool firms are clustered together in industrial districts: Piemonte and Lombardia (Italy), Baden Württemberg and North Rhine Westphalia (Germany), and the Tokai Region (Japan) (see maps in Appendices A through C). To give a clearer sense of the extent of this clustering, the single German state (Land) of Baden Württemberg has roughly the same machine-tool production capacity as the entire United States. Within these industrial districts, SMEs may work together in areas of mutual interest. The Italian machine-tool industry has few large firms and low R&D spending, but has succeeded in adopting new technologies, thanks to close relationships among firms, which enable them to specialize in particular components (see Appendix C). In the Japanese case, Friedman (1988) cites an extreme example of small job shops that band together to prevent large buyers from playing firms off against each other to lower prices; these job shops, which may only contain a single CNC machine, will sometimes share spare capacity if another firm needs it to make an order deadline. Publicly supported institutions facilitate cooperation among the firms by acting as intermediaries and providing an array of services (vocational training, applied research, technology transfer, export marketing) that are crucial in the new global competition for machine tools but would be beyond the means of an individual SME (Sabel, 1989; see next section, on Technology Development and Transfer, for more details). These institutions depend on local employers for a large part of their funding and thus must remain responsive to their needs.

It is important, however, not to overemphasize the extent of cooperation among machine-tool makers in these regions. These companies continue to compete in both domestic and foreign markets and jealously guard their R&D and other perceived sources of competitive advantage. It is this competition that some argue is the key to the success of these industrial districts (Porter, 1990), as it forces firms to remain innovative. The nature of this competition, however, is closely regulated by the cooperative organizations. Firms are encouraged to compete on the basis of product differentiation, quality, and new innovations, rather than undercutting each other on price (Friedman, 1988; Herrigel, 1993b).

This picture stands in contrast with the United States, where the machine-tool industry is also composed predominantly of small companies. Using our expanded definition of the industry (see Chapter Two), 73 percent of the companies in the machine-tool industry had fewer than 50 employees in 1989 (see Figure 4.4). Like their main competitors, U.S. machine-tool firms are clustered geographically, although not as regionally concentrated as in Japan and Europe. The map in Figure 4.5 shows the number of plants whose primary or secondary product is machine tools, with each dot representing a separate establishment. U.S. machine-tool firms are

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10 Determining the number of firms in the U.S. machine-tool industry depends on how the industry is defined and what data source is used, with estimates ranging from 120 companies (Gordon and Krieger, 1993) to more than 1,500. These data are taken from the Donnelley firm’s database and include all plants making machine tools. No previous data source has included firms that make machine tools but do not list them as their primary product.
Figure 4.4—Machine-Tool Establishments by Number of Employees, 1992
(expanded definition)

Figure 4.5—Locations of U.S. Machine-Tool Plants
clustered near the large aerospace and automotive manufacturers (e.g., Los Angeles, Seattle, and several areas in the Midwest). What separates the United States from its main competitors is that firms in these clusters are generally wary of cooperating. Among the reasons for this are antitrust regulation, which until recently prohibited any form of collusion; an unwillingness to share proprietary information; a lack of export orientation, which means firms tend to be vying for the same domestic customers; and a traditional American belief in the free market and independent entrepreneurs. A good example of the latter attitude was provided in one of our industry focus groups by a successful new small machine-tool maker, which built a new factory next door to its closest rival: "I can see the arguments for cooperating, but my guess is we never will."

One reason for the low cooperation among U.S. machine-tool manufacturers has been a lack of an effective mechanism for setting and implementing technical standards, which in turn inhibited the development of commodity CNC technology. During the 1960s and 1970s, the U.S. machine-tool industry's emphasis in NC was on expensive, specialty equipment for the aerospace industry (one-third of the CNC market in 1970) and, to a lesser extent, large automobile manufacturers. The standards imposed by the Air Force in its early R&D and procurement programs for NC tooling aided the diffusion of these high-end specialty systems. During this period, however, machine-tool makers were not able to generate a mass market for low-cost NC machines among the small job shops that dominated the U.S. metalworking industry. In the 1960s, U.S. firms debated whether machine-tool makers should manufacture their own controllers but had no effective vehicle for coordination, with the result that at least ten machine-tool firms and five outside suppliers developed control units. Most CNC technology was proprietary, making equipment integration and substitution difficult and expensive. This diversity of controller technology slowed the diffusion of NC throughout U.S. industry by increasing the risk of obsolescence for early adopters and increasing the complexity and cost of the controller units, as no one U.S. manufacturer attained sufficient economies of scale. The U.S. industry association felt restrained from proposing standards that would have reduced these problems because of the threat of antitrust action. These antitrust restrictions were not substantially relaxed until the mid-1980s.

In contrast, Germany and Japan have pursued more active standard-setting policies. As noted in Chapter Three, MITI used a combination of quality standards, product licenses, and investment incentives to help spread the diffusion of CNC and make FANUC the control standard for Japan and the rest of the world. The industry associations in Germany sponsor a system in which major industry players meet together to set the standards for different types of machines. An expert on the German machine-tool industry describes this standard-setting process as a way for employers to divide the markets they have defined so that only a few producers focus on any

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11 RAND interviews, focus groups, and site visits; see Herrigel, 1993b. We identified some exceptions, such as the manufacturing cooperative association in Wichita.

12 This discussion is largely drawn from Collis (1986).
one specific market segment. This system, which has developed over the course of many years, aims to avoid disastrous price competition among German firms, particularly during economic downturns. These standards are enforced by the industry association, which can impose a variety of sanctions (including denial of the "Made in Germany" seal of quality) on those firms that refuse to abide by the system.

TECHNOLOGY DEVELOPMENT AND TRANSFER

The United States, as noted earlier, pioneered the development of CNC technology, but lagged behind its foreign competitors in widespread adoption of the new machines. There are multiple causes of this technology diffusion problem; as we argue in later sections, U.S. machine-tool firms also lacked the internal capital investment and the skilled shop-floor workers and engineers necessary to keep pace with new technology. But in industries composed of small firms, the rate of technology adoption strongly depends on the extent to which those firms form linkages with external sources of technological expertise (Kelly, 1991). U.S. machine-tool firms have weak links not only among themselves but also with other potential external sources of technology.

Poor Technology Links to Customers

Machine-tool users are the most important external sources of new technology for U.S. machine-tool firms, as shown in Figure 4.6, based on a survey of 35 machine-tool firms (Gordon and Krieger, 1993). Nearly 80 percent ranked their customers as their "most significant" source, and about 60 percent ranked competitors, trade fairs, and control equipment firms as "significant" or better sources. Despite the world-class manufacturing technology developed in U.S. universities and government research institutions (see Appendix F), less than 10 percent of machine-tool firms reported that these institutions were important sources of new technology for their products.

Machine tools, like most forms of complex industrial equipment, have several characteristics that suggest that close communication and interaction between machine-tool makers and users should be an important conduit for technology (Gertler, 1993; Carlsson and Taymaz, 1992b). 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 the process will often involve sharing proprietary information. This approach has been successfully applied by U.S. firms such as Ingersoll International and H. R. Krueger (see Appendix E). In addition, a close relationship between maker and user can facilitate the different steps required to get a machine operating at peak efficiency: installation, training, start-up, and debugging of the equipment (Gertler, 1993; RAND focus group).

13Gary Herrigel, 1993 interview.
14German standard-setting practices would violate not only the letter but the intent of U.S. antitrust statutes. To some extent, the standard-setting process in Germany serves as a cover for cartelizing the market. The "standard setting" process not only promotes uniformity; it also discourages entry.
Despite the potential advantages of close links and their ranking as the most important external source of technology, customers were not a good source of new technology for most U.S. machine-tool makers during the 1980s (RAND firm visits and interviews). Relations between U.S. machine-tool makers and users are generally through arm’s-length transactions, with a heavy emphasis on price (Herrigel, 1993a; Gordon and Krieger, 1993). This type of relationship is not conducive to an easy flow of technology. Less than one-fifth of the machine-tool makers in the Department of Labor survey had any form of partnership or strategic alliance with a customer, and none of these were set up to share financing or R&D costs (Gordon and Krieger, 1993, p. 25). On the contrary, users typically ask machine-tool makers to cover the full costs of new product development, which can take up to two years, withholding payment until the tool is successfully installed and tested in their factory (RAND focus group). This stands in stark contrast with Europe and Japan. In Germany and Italy, up-front deposits and in-process payments have been the norm, and machine-tool makers work closely with customers, particularly in the Italian industrial districts (see Appendix C). In Japan, large machine-tool users will sometimes place technical staff in a machine-tool maker to cooperate in the design of a new machine (RAND interviews).

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15None of the strategic alliances included small machine-tool makers, the firms presumably in greatest need of external support (Gordon and Krieger, 1993, p. 25).
The main exception to the rule of short-term, arm's-length transactions between U.S. makers and users is the defense and aerospace industries, where the two sides have historically worked in close cooperation. And it is in these sophisticated sectors that some U.S. machine-tool makers, such as Ingersoll and the Advanced Machine Tool Systems Group at Cincinnati Milacron, have maintained a strong competitive position. The concentration of the United States' surviving machine-tool makers in the high-value-added end of the market is evident from a comparison of the average dollar value of tools sold in the United States by foreign and American firms (see Figure 4.7). In 1991, U.S.-produced tools averaged more than $100,000, roughly twice the average price of imported tools.

Poor Links with Government-Sponsored Research

Beyond customers, another possible source of technology is government-sponsored research. But, like many other U.S. industries, the machine-tool industry derived little benefit during the 1980s from the large federally supported activity in science and technology. Although government funding is the primary support for world-class basic research on manufacturing in U.S. universities and federal laboratories, as Figure 4.6 indicates, little of this technology has proved important for U.S. machine-tool firms. This message was reinforced during our study. Few machine tool-makers had active relationships with universities or laboratories, and they could not point to commercial products that had derived from work at such institutions.

![Figure 4.7—Real Cost per Machine Tool of U.S. Exports, Imports, Production, and Domestically Consumed Production](image)

NOTE: Includes only new complete machines valued over $2,500 through 1990 and $3,025 through 1991.
One major difficulty is that much federal R&D has focused on specialized defense products, and less than 2 percent of funds has gone to improving the manufacturing process (Alic et al., 1992). The major exception to this product focus has been the Department of Defense's (DoD's) Manufacturing Technology (ManTech) program, designed to promote the development and application of new manufacturing processes among DoD suppliers. The Air Force has been the main actor in ManTech, providing 50 percent of the total funding. The program spent $1.9 billion between 1978 and 1990 (Alexander, 1990), with about one-quarter going to the machine-tool sector. While playing a role in advancing manufacturing technology in the aerospace industry, ManTech was neither designed to address nor had much impact on the main factors that caused the decline of the U.S. machine-tool industry during the 1980s. ManTech-funded projects specifically focused on military applications, often without broad commercial utility, and had no well-developed mechanisms of technology transfer to firms beyond the defense contractors that were the main program participants (National Academy of Sciences, 1986).

For instance, ManTech's Intelligent Machining Workstation (IMW) Initiative successfully developed advanced technology to create process plans and CNC programs from the designs of parts. The IMW also developed hardware and software that potentially would allow a machine tool to build for itself any special fixtures needed to manufacture the part. This technology was far ahead of anything industry was willing to adopt, and little technology transfer occurred, despite an industry and university review board intended to guide the research according to a prioritized list of industry needs (see Appendix D for more details).

ManTech initiatives have also suffered from the complexities of the defense procurement process, in that most of the funds flowed to DoD prime contractors and a few large machine-tool firms. Small firms complain that the difficulties of navigating the government procurement process have generally made it not worth their while to participate in such programs as ManTech (RAND focus groups). Representatives of several machine-tool companies cited instances in which DoD contracts for new machine-tool systems were won by the firms most skilled at the procurement process rather than those with the best machine tools. ManTech has tried to correct such problems over the years, with limited success.

U.S. universities are also world leaders in research on many new manufacturing technologies. Nonetheless, this technology leadership has had limited value for U.S. machine-tool firms. In part, U.S. universities, with a few notable exceptions (e.g., Purdue, Lehigh), have neglected issues of manufacturing process in favor of product design and a more theoretical, science-based curriculum (Dertouzos et al., 1989, Vol. 2, p. 29). Firm representatives complain that university professors and their students had little shop-floor experience and often little interest in their problems, while manufacturing "engineers" on the shop floor often lack even a bachelor's-level engineering education (discussed below in the section on skills) (RAND focus groups). In

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16 A significant portion of this budget was directed to sectors other than machine tools. In 1986, for instance, 20 percent of the funds went to electronic integration and assembly, and 23 percent to Air Force maintenance activities.
addition, the incentives, and hence the agendas, of university researchers are very different from those motivating industry researchers, especially those in small- and medium-sized firms. Academics are generally encouraged to specialize in a narrow area to gain tenure, while industry innovation requires a broad understanding of the manufacturing process. Likewise, academics' tradition of open publication conflicts with industry's desire for proprietary rights. These observations are supported by the experience of several state-level programs developed during the 1980s to foster collaborative efforts among university and industrial researchers. The programs that left the research agenda under control of university faculty generally found that the product was much less useful to firms than was the university research conducted according to a private-sector-generated agenda (Osborne, 1990).

**Japanese and German Technology Transfer Programs**

To understand the U.S. machine-tool industry's relatively weak opportunities to obtain technology, it is useful to compare it with the situation in Japan and Germany. Both foreign governments have been far more effective at promoting applied R&D and the transfer of technology, particularly to small- and medium-sized firms. The Japanese government supports many applied industrial research programs; some of the supported work is carried out in universities or government laboratories, but the bulk takes place in industrial laboratories. Japan's *Kohsetsushi*, 170 regional technology centers in a nationwide network, provide a variety of services to local firms, including applied research, compliance testing, seminars and other information dissemination, consulting on problem solving and the implementation of new technologies, training, laboratory space for prototype development, and promotion of networks among regional firms. Each *Kohsetsushi* specializes in a technology area based on the interests of the region's firms and is primarily supported by prefectural and local government. The national government contributes 20 percent of the system's $500 million annual budget (Shapira, 1992).

The German government also spends significant research money on applied technology (see Appendix B). The Ministry of Research and Technology (BMFT) is the main government organ funding industrial technology; such support is distributed among industry, universities, quasi-public research centers (Fraunhofer Institutes), and other technical consulting bureaus operated by industry associations, often in conjunction with the German engineering association. Since 1980, BMFT has spent over DM 1 billion on programs in production technology, aimed most recently at advancing CAD, computer integrated manufacturing (CIM), and robotics technology. Past programs were very successful in spreading CNC technology throughout the German manufacturing sector. Before 1980, most German applied research funds were spent on single projects in large research institutions. Since then, the German government has made a concerted effort to promote innovation in small- and medium-size firms by distributing its research support more broadly. Accordingly, the production technology program included incentives for networking among SMEs and funds for technology transfer programs. During the mid-1980s, two German ministries (BMFT and the Economic Ministry) also spent DM 3.5 billion providing wage subsidies to research personnel in small- and medium-sized German firms.
These programs have much higher participation rates than those in the United States. For instance, in Baden-Württemberg, about 70 percent of machine-tool firms participated in the federal research programs in CNC and CIM technology.

A key to the success of Germany’s technology transfer system in reaching SMEs is the government’s reliance on quasi-public organizations to provide services. These organizations include the Steinbeis Foundation, chambers of commerce and industry, and the Rationalization Committee of German Industry. In 1992, for example, the Rationalization Committee of German Industry alone provided state-subsidized training and consulting on such issues as process control and organizational flexibility to more than 6,000 firms. These decentralized organizations not only provide an efficient, flexible delivery of government programs but also help build strong regional employer networks.

A Successful Technology Transfer Mechanism: The Fraunhofer Institutes

One of Germany’s most important applied research and technology transfer vehicles is the Fraunhofer Institutes, a network of 45 research and service organizations. The Fraunhofer Institutes employ over 7,600 people, one-third of whom are engineers, with a total budget of DM 821 million. Each center has a particular specialty; the centers at Aachen, Berlin, and Stuttgart focus on production equipment and process technologies. The institutes are normally affiliated with research universities and focus on contract research performed for industry, typically large companies, or government. In addition to this applied research, the institutes also contribute to the technology transfer process through the frequent exchange of personnel with industry, as Fraunhofer researchers are highly sought after by the private sector.

The Fraunhofer Institute for Production Technology at the Technical University of Aachen, for example, is very highly regarded for its work in processing new materials. It has a research budget of about $15 million to 20 million per year, which is roughly matched by the research volume in the manufacturing research laboratory at the Technical University of Aachen. These two institutions are literally next door to each other, have the same senior management, and share staff and facilities. One-third of the combined $30 million to 40 million budget comes from federal/state base funding, one-third from industrial contracts, and one-third from federal/state contracts. Compared to the university manufacturing research laboratory, the Fraunhofer laboratory emphasizes more applied research. But the two organizations also have separate areas of technical emphasis, with traditional machine-tool technology in the former and processing of new materials, such as ceramics, in the latter. The Fraunhofer has strong ties with industry, and in particular with Ford and United Technologies in the United States. Ford is actively considering the establishment of a European Research Center in Cologne, which is near Aachen, primarily because of the proximity to the Fraunhofer.

For details of their activities, see Appendix B.
Summary

In the critical area of technology development and transfer, then, the U.S. machine-tool industry faces two formidable obstacles. Poor links to customers limit the amount of technology that can be obtained from this primary source; poor links with government-sponsored research programs and the emphasis of those programs limit the value of this large federal investment for the machine-tool industry. U.S. competitors abroad, in contrast, enjoy close relationships with both their customers and publicly funded research centers.

WORKFORCE SKILLS

As we have seen, the United States has been markedly less successful in adapting to the new CNC technology than Germany and Japan. The United States not only has much lower rates of investment in the latest flexible technology, but has also tended to take a lower-skill approach to introducing CNC tools. That is, by adapting the new technology to compensate for low-skilled workers in many functions, machine-tool makers and users fail to receive the full economic benefits that these technologies offer their foreign competitors.

Managers' choice of skill strategy is influenced by both the internal and external institutional environment in which they operate. As the following sections will show, the United States has low levels of general education, a lack of occupational training, few engineers in the sector, and poor incentives for in-firm training. This has led U.S. managers to pursue a lower-skill strategy with the new technology than their main rivals do, which in turn discourages the most able young people from entering metalworking. The result, as illustrated in Figure 4.8, is that U.S. machine-tool makers and users have been trapped in a vicious circle of low supply and demand for skills.

Figure 4.8—Skills and the Use of New Technology
Low Levels of General Education

The U.S. skill problem begins in the general education system. As shown in both in-depth classroom comparisons (Stevenson, 1992) and international standardized tests (IEA, 1987), the United States is less successful in providing the majority of students with a foundation of literacy, mathematics, and scientific skills than its counterparts in many other nations. Machine-tool industry representatives consistently rated the lack of basic skills and the perceived antimanufacturing bias of students leaving the U.S. public education system as the most pressing human resource problems facing their industry (see Appendix G). This contrasts with Japan and Germany, where manufacturing continues to be held in high prestige and where machine-tool makers and users can recruit from a pool of young people who have, in many cases, mastered two languages and advanced math and science (Dore and Sako, 1988; Prais, 1990).

The U.S. problems in compulsory education are compounded by a failure to provide high-level occupational skills for those not completing college degrees. As Figure 4.9 indicates, the United States produces fewer individuals with scientific and technical qualifications than its main rivals.¹⁸ The gap is most glaring at the craftsman level: The German apprenticeship system produces more than four times as many skilled workers (on a percentage-of-population basis) as the United States. And U.S. metal-

![Diagram showing proportions of population qualifying in engineering and technology, 1985](RAND MF787/4.9)

**Figure 4.9—Technical Manpower in the United States, Japan, and Germany**

¹⁸These statistics are based on research by the National Institute of Economic and Social Research in London and RAND analysis of U.S. Department of Labor figures on registered apprenticeships. These data, from the Department of Labor, may exaggerate the actual skill gap because many U.S. manufacturers fail to register their apprentices.
working firms are not closing the gap for skilled workers; on the contrary, the number of registered machinist apprentices, already at a low level, has declined in the last decade to less than 0.1 percent of employment in the sector. This is despite the fact that there is too small a supply of trained machinists to replace the generation now retiring.

Neither is the lack of skilled production workers in the U.S. machine-tool sector offset by a large supply of engineering graduates. As shown in Figure 4.10, the U.S. machine-tool industry not only employs fewer engineers than the average for U.S. manufacturing, but it also has far fewer engineers than Japan. The lack of engineers in the U.S. machine-tool industry is even more apparent if we look more closely at the statistics—more than half of those who described themselves as “engineers” in the Current Population Survey (CPS) had not been in full-time education long enough to graduate from college. Even those engineers who do obtain a degree

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19 The data on apprenticeship decline come from analysis of the Current Population Survey. The cause of the decline in apprenticeship is not a lack of interest from employers: A 1987 AMT survey of its members revealed that 90 percent of machine-tool makers favor an increase in apprenticeships; only 10 percent of these firms, however, had even one apprentice, despite an AMT program that offered every member firm a scholarship to pay the full costs of off-the-job training for an apprentice each year.

20 Earlier studies of the machine-tool industry predicted that there would be a rapid aging of the production workforce, including an average age of machinists projected as 58 by the year 2000 (National Research Council, 1983). Our analysis of the Current Population Survey, however, reveals this aging of the workforce has not occurred; instead, metalworkers appear to have replaced the retiring machinists with a combination of less-skilled operatives and technicians recruited from colleges.

21 These figures must be interpreted with caution, since the sample of Japanese firms includes only a small number of their largest machine-tool makers (Sciberras and Payne, 1985); the U.S. data are taken from RAND analysis of the Current Population Survey.
are often criticized by machine-tool firms for lacking the applied experience that is crucial to generating the types of innovations needed in this sector (RAND focus groups and interviews).\textsuperscript{22} In sum, there is a relatively low supply of skills, at all levels, flowing from the U.S. education system into the machine-tool industry.

The Lack of In-Company Training

The next stage in the vicious circle of low skill levels is the relative lack of in-company training. A number of factors deter U.S. machine-tool firms from making a major investment to upgrade the skills of their workforce. One of the most significant may be “poaching”—the risk that the firm will spend the time and money required to train a skilled machinist, for example, only to have him hired away by a competitor or machine-tool user.\textsuperscript{23} While it is difficult to document the impact that the threat of poaching has on company-based training, our interviews revealed several concrete examples. Until the 1970s, Cincinnati Milacron had a well-respected machinist apprentice program. The company abandoned the program, however, when it could no longer justify the costs relative to the numbers it was retaining. The normal rate of attrition shot up when a nearby defense contractor began offering a bounty of $1,000 to anyone who could convince an apprentice graduate from “The Mill” to come work in its plant.\textsuperscript{24}

The small- and medium-sized employers who make up the bulk of the machine-tool industry not only face the risk of poaching by larger, better-paying firms, but would, in any event, have difficulty providing the broad training experience that apprentices require. Other factors deterring machine-tool firms from training for higher-level skills include the historically cyclical nature of domestic machine-tool demand, which results in periodic layoffs, and the low levels of basic skills of many entry-level workers, which mean that when firms do invest in training, it often goes to provide basic literacy and numerical skills.

Again, comparison to the United States’ main machine-tool competitors underlines the problem. Many foreign firms have strong institutional incentives to invest in broadly training their workers. In Japan, this is normally accomplished through systematic job rotation and close cooperation among machine-tool makers and their suppliers and customers.\textsuperscript{25} The promise of lifetime employment, still prevalent in the Japanese machine-tool industry, makes it difficult to poach skilled workers, since

\textsuperscript{22}Trumpf U.S.A., for example, puts its graduate engineers through an accelerated one-year apprenticeship program, because it feels they are missing sufficient applied skills.

\textsuperscript{23}Traditional human capital theory argues that poaching should not be a problem because individuals should pay for the cost of general skill training. Recent theoretical work (Stevens, 1994) suggests that poaching may be a problem for skills, like those of machinists, that are transferable among a specific sector of firms. In practice, firms that take on apprentices spend a significant amount on training that is transferable to other metalworking companies.

\textsuperscript{24}H. R. Krueger abandoned its apprenticeship program during the 1970s for similar reasons. Poaching has become less of a problem during the last few years, because machine tool firms have been downsizing, along with the auto and defense industries, which has increased the supply of unemployed machinists.

\textsuperscript{25}RAND interviews. Makers offer training to machine-tool users as a service and to suppliers as a means of improving quality and price.
such recruits would disrupt the internal labor-market structure. A Japanese Ministry of Labor program that subsidizes companies that have been hard hit by a recession to retain their employees creates two additional incentives for firms to invest in skills: Not only are firms who take the subsidy obligated to train the designated workers, but these firms are also more likely to train when demand recovers, because they know they will not have to lay off workers during recessions.

In Germany, the large employer investment in training takes place primarily through the world-renowned apprenticeship system, the entry route for virtually all production workers, as well as for many of the managers who now run German machine-tool firms. There are a number of reasons why German machine-tool makers are willing to make the major investment in machine-tool apprentices, despite sometimes losing their newly skilled workers to larger firms. First and foremost, the nature of their product strategies and work organization demands high levels of skill if they are to continue to maintain high quality and innovation. Second, the costs of the German “dual system” of apprenticeship are equitably shared, with individuals accepting a low allowance during the training period (ranging from 25 to 50 percent of the adult production worker’s wage) in return for the qualification they acquire, while the state covers all the off-the-job training costs. Third, the chambers of commerce and industry collect compulsory dues from all companies to support the administration of the apprenticeship system (e.g., administration of exams, monitoring of in-firm training) and apply informal pressures to firms that are not carrying their share of the training burden. Because apprenticeships are the dominant route for those not attending university, it is only by participating in this system that firms are able to gain access to the most able young workers, with no obligation to retain the apprentices they do not want at the end of the apprenticeship period. In addition, the German government uses the tax system and targeted subsidies to encourage firms to maintain skill investment during recessions.

Low-Skill Use of New Technologies

With low-skilled workers and little incentive to provide training themselves, U.S. machine-tool firms thus face a dilemma: Obtaining flexible and highly skilled workers is difficult, yet batch or customized production systems demand high levels

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26 The major Japanese machine-tool makers are able to sustain the lifetime employment bargain, despite the highly cyclical nature of the machine-tool industry, because they tend to outsource more production than their German or U.S. rivals, tasks that they make take back in-house during recessions (RAND focus groups). For example, Mazak, one of the largest Japanese machine-tool makers, has a policy of outsourcing at least 20 percent of every major component in its machines to ensure that its in-house operations remain competitive (see Appendix A).

27 Recognizing that the traditional apprenticeship, with its emphasis on a narrow range of craft skills, was inappropriate to the new production environment dominated by programmable machines, the Germans chose metalworking as one of the first major occupational categories for apprentice reform. After a decade of development and negotiations between employers and unions, 37 engineering qualifications were reduced to seven broader occupational categories (Casey, 1990, p. 26). Each trainee starts with hands-on metalworking, while learning a combination of the general math and science that underpins the practical work, along with computer programming and design. The fact that apprentices continue to account for nearly 10 percent of the total machine-tool workforce provides evidence of the continued vitality of the dual system (see Appendix B).
of skill and flexibility. Many have coped by devising an alternative work organization and skill strategy to that of their Japanese and German competitors: polarizing the skills in the workplace. According to three recent surveys of Michigan and Wisconsin metalworking firms, such companies use the CNC technology to centralize control over most programming, thereby upskilling technicians, set-up men, and programmers to oversee the manufacturing process, while machine operators and assemblers receive little training (Jacobs, 1991a, 1991b; Rogers and Streeck, 1991). The Detroit study, the only one to ask specifically about machine-tool operators, found that the majority of firms required only basic skills, assuming that “this group will possess essentially the same skills as twenty years ago” (Jacobs, 1991b, p. 52).

This general strategy varies by firm size, with smaller companies, particularly those in high-quality markets, less likely to divide tasks in this way and therefore more likely to use CNC to increase the skills of operators and machinists (Kelly, 1990). But small firms are also less likely to invest in the latest technology. A 1987 survey of U.S. machine-tool users found that less than half of firms had even one CNC machine and that only 16 percent of those with CNC offered workers classes in how to program the new machines (Kelly, 1991). The effect of the low external supply of skills on managers’ decisions was clearly shown in the Wisconsin study: Most managers said “no” when asked if they were experiencing a shortage of skills for their current work organization but “yes” when asked if they would organize work differently if they had an available supply of high-skilled workers (Rogers and Streeck, 1991).

Japanese and German companies take a different approach to the latest technologies, placing a heavy emphasis on the skills of frontline workers. 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 (who are scattered throughout their operations, not sequestered in the R&D department), but production workers as well. Said one leading distributor of both U.S. and Japanese machine tools:

The Japanese will purchase the latest million-dollar flexible manufacturing cell and put an engineer on it for the first few weeks to ensure that it is operating properly and to search for any ways of improving its performance. A typical U.S. firm will stick an operator on it whose only skill is knowing the difference between the red and green buttons [to turn the machine on and off]. Then they wonder why they don’t get the expected return on their capital investment (RAND firm visit, 1993).

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28Our analysis of the educational attainment of different metalworking occupations taken from the CPS reveals a significant increase in the educational levels of technicians; the proportions in the different occupations remain unchanged, however.

29Our case studies of two of the most successful new U.S. machine-tool makers showed the danger of equating formal training with skill levels. Both firms have training departments, but use them exclusively to train the users of their tools, providing no formal training for their own employees. Yet these companies, both family-owned SMEs, place a high value on their employees and support worker learning. For example, each new manager or engineer hired by one firm spends the first year rotating through all the different jobs in the organization. When a worker does not have the skills for a particular task or new machine, he or she is encouraged to seek the help of a fellow employee. These types of informal learning do not turn up in formal training statistics, but may be the most common form of skill acquisition in the United States (e.g., Lillard and Tan, 1986).

30Note that the cost to firms associated with this lack of training is not captured by the traditional measure of skill shortages—e.g., unfilled vacancies for skilled positions.
Negative Consequences of Low Skill Levels

There are a number of ways in which the vicious circle of low supply and demand for skills may be hurting the competitiveness of the U.S. machine-tool industry. Without a broadly skilled workforce to replace the old generation of machinists, it will be difficult to generate the continuous product and process innovations that are critical to success in machine tools. Another potential sign of the problem is the low rates of labor productivity, which actually declined in real terms throughout the 1980s (see Chapter Three). The lack of basic skills also compels firms to invest in remedial training and may lead to higher wastage rates and increased machine downtime as a result of poorer maintenance skills (Jacobs et al., 1991b; Kelly, 1990). The low level of skills among machine-tool users may also have contributed to U.S. firms’ slower adoption of CNC technologies than Germany and Japan and the disappointing rates of return on this investment that many have reported (Jalakumar, 1986; Jones, 1989).

The comparison with Germany and Japan is obviously important, because these nations lead the machine-tool industry worldwide. But, ironically, the danger for the United States posed by the vicious circle of low skill supply and demand may come not so much from these already higher-skill machine-tool makers but rather from rising machine-tool powers, such as Taiwan and eventually China. Firms in these nations can adopt production strategies similar to those of many U.S. machine-tool makers while paying workers a fraction of American wages and benefits. In summary, if the United States is to keep pace with technological change and remain a competitive site for manufacturing machine tools, it must upgrade the level of skills entering the sector and invest more in the training of existing workers.

CAPITAL INVESTMENT

The final key input to the machine-tool industry is investment capital. Lack of investment both in the machine-tool industry itself and within the industries that buy machine tools has been a serious problem over the last decade. During a period when manufacturers worldwide are retooling to take advantage of CNC machines, purchases of new machine tools in the United States have lagged depreciation over the last several years, as shown in Figure 4.11. Since the early 1980s, even as product cycles in manufacturing equipment elsewhere have gotten shorter, the installed base of machine tools in the United States has been getting older (see Figure 4.12).

The use of CNC machine tools within U.S. machine-tool builders themselves is disturbingly low. The lack of CNC equipment has hurt the manufacturing efficiency and flexibility of these firms. Rather than make machine components as needed using easily programmable CNC tools, firms using conventional machines will make large batches of parts for stock. Lack of capital has also hindered machine-tool makers

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31 There are many possible causes of low labor productivity besides skill levels: The low rates of capital investment; fall in demand exceeding declines in employment; greater competition forcing down tool prices; and a measure that does not capture the improvements in machine-tool quality and capability. Nevertheless, the productivity gap between U.S. firms and Japanese and German firms is striking.
Figure 4.11—Machine-Tool Purchases and Depreciation in Major Machine-Tool–Using Industries

Figure 4.12—Average Age of Machine Tools
from installing and testing their own flexible manufacturing cells and benchmarking them against competitors, while stymieing research and development. Capital constraints make selling CNC machines more difficult, because customers see the lack of the latest machines within the builder’s plant as an indication of poor technological sophistication, and lack of working capital reduces the ability to export.

The capital access problems of the machine-tool industry are not unique among U.S. industries composed of small- and medium-sized firms. (Capital access may be somewhat more important for machine-tool producers, because their production processes are capital intensive, and their product is a capital good often sold to other small- and medium-sized manufacturing firms.) Capital access problems arise because of the small scale of machine-tool firms, industry structure and practices, regulation of financial markets, and details of the tax code.

Not a Cyclical Problem

Before exploring the primary factors that cause machine-tool firms’ capital access problems, it is important to understand two factors that might be blamed but that are not, in fact, central to the problem. The first is general economic cycles; the second is overcapacity in the industry.

The financial problems of the machine-tool industry were not caused by a lack of credit in the economy as a whole. Figure 4.13 shows that net credit flows to non-

![Credit Availability and Machine-Tool Sales](image)

NOTE: Funds raised are net of repayments and can be negative.
financial businesses were at historically high levels during the worst years for the machine-tool industry. Investment in manufacturing was also strong during this period (see Demand section of this chapter). Although the economy went through a credit crunch during the late 1980s and early 1990s, this occurred well after the troubles in the machine-tool industry began. A sudden withdrawal of credit cannot be blamed for the industry’s ills. Rather, persistent difficulties of small- and medium-sized businesses in obtaining adequate credit may impede their ability to compete in a quickly changing global economy.

**Overcapacity and Underinvestment**

Overcapacity within the machine-tool industry was one cause of low investment through the 1980s. The collapse of the machine-tool industry at the beginning of that period was in part demand driven: Domestic purchases of machine tools fell precipitously, then stagnated. Because of the greatly reduced U.S. demand for machine tools, significant overcapacity existed in the industry; this was eliminated largely through the elimination of machine-tool firms. Figure 4.14 shows capacity utilization in the nonelectric machinery industry.\(^\text{32}\) From 1982 through 1988, capacity utilization remained below the bottoms of the extreme cycles of the 1970s. During such a period, many U.S. machine-tool makers saw little incentive to invest

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\(^{32}\)This category includes machine tools and is the closest category to machine tools on which the Federal Reserve collects data.
heavily in modern plants and equipment. If a firm did not have excess capacity itself, it could easily buy used equipment at pennies on the dollar. Even firms that wanted more advanced equipment were largely shunned by the financial community, because industry overcapacity was coupled with low industry profits.

As the overhang of capacity was drawn down, many U.S. machine-tool firms found themselves with antiquated equipment, little experience in using advanced CNC equipment, and consequently, a large gap in skills and experience in producing such equipment. Lagging best practice was cheaper for many firms, at least in the short run. While this has been a continuing technological drag on the industry, the industry may have reached bottom in this downward spiral of excess capacity. Similar problems existed in the broader metalworking sector in the United States.

Scale

One of the problems that does currently limit capital access of the machine-tool industry (and other industries composed of small- and medium-sized firms) is simply size. While the U.S. financial markets provide large flows of funds at low cost to large borrowers, the markets are less successful at funding smaller borrowers at reasonable cost. This is because the capital needs of small- and medium-sized businesses are so small that processing and transaction costs may be a noticeable fraction of capital they are seeking. The high cost of generating funds in the formal financial markets leads small- and medium-sized businesses to depend heavily on two sources of finance: retained earnings and capital from family and friends. Both these sources are idiosyncratic, and firms cannot depend on them to exploit business opportunities, develop promising new products or processes, or ride out business cycles. Borrowing working capital and borrowing for specialized equipment can be particularly costly for small- and medium-sized businesses. One banker revealed that it might cost as much as $20,000 to process an $80,000 loan to a small firm. Even firms with confirmed export sales may still not be able to obtain the credit necessary to finance the orders; some have begun turning to Japanese trading companies to

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33 In other words, there are fixed costs of borrowing or issuing new equities. Businesses with limited needs for capital must spread these costs over a small loan or equity issue. Their costs are consequently high.

34 The machine-tool demand is particularly sensitive to changes in overall economic conditions. During the 1970s, the wide swings in machine-tool demand were viewed as the bane of this industry. After the large decline in 1982, cyclical swings have been less pronounced, because overall demand has remained at very low levels.

35 Working capital is problematic because, unlike lending for plant, equipment, and property, which can be collateralized, working capital is "secured" by the business prospects of a company. It is much easier (and hence cheaper) to assess the value of a structure or piece of equipment than it is to assess the prospects of a company. The latter requires detailed knowledge of the company and its markets. There is an active commercial paper market to fund larger businesses where the size of the borrowing justifies outside expertise on the prospects of borrowing firms.

36 Borrowing for specialized equipment is difficult, because a lender may have difficulty even understanding what the equipment does, let alone what else it might do and consequently what it might be worth as collateral. This is the same reason that it is easier to borrow money to buy a car (standardized) than for a house (specialized). An extremely specialized piece of equipment may have no alternative uses other than scrap, so lending for purchase of such equipment is similar to lending for working capital. Niche lenders have emerged that will fund the purchase of machine tools.
provide a service that no U.S.-based financial institution was willing to take on.\textsuperscript{37} Size also limits the ability of firms to take advantage of government programs designed to assist them, because no one in the firm has the time to learn about and fill in the necessary paperwork (RAND interviews).

Despite these difficulties, the problem is not so much that funds are unavailable as that finding them is difficult. In almost all cases, sources of funds existed for creditworthy borrowers, even if they were small firms. These sources include specialized lending institutions that understand either small firms, their industry, or both; venture capitalists; or good loan officers at less specialized banks. In some cases, state and local governments, as well as cooperative lending institutions, are potential sources of funds. Even though funds were available for creditworthy borrowers, many machine-tool firms, like many other small- and medium-sized businesses, fail to connect with satisfactory sources of capital. The difficulty facing a small firm is in finding and maintaining appropriate sources of funds. While a major corporation may have a large financial department, a small- or medium-sized manufacturer may have one person in charge of finance who also does the time cards, the payroll, the bookkeeping, the taxes, and in some cases, is also the president and owner of the firm. One nearly universal aspect of success stories—those small- and medium-sized firms that have found a good banker or other source of funds—is that success came after a very long search process. Some businesses have reported talking to 50 or 60 financial institutions before finding a good match; even then, high turnover rates among loan officers may jeopardize the relationship.\textsuperscript{38} Many small firms just cannot afford this much diversion of management attention.

Industry Structure and Practices

Not all machine-tool producers are of insufficient size to take advantage of capital markets. The industry runs the gamut between a majority of small, family-owned concerns that finance themselves out of retained earnings to a few larger firms with up to 2,000 employees. Larger, publicly traded companies face pressures for short-term results in an industry where long-term presence and the ability to ride out business cycles is important (Porter, 1992). This short-term pressure was particularly hard for the conglomerates that acquired machine-tool firms in the 1960s and 1970s (see earlier discussion of industry structure).

Other practices within the industry have led to particular problems for small firms. Few customers are willing to make work-in-progress payments for large projects, and banks are loath to lend large sums to small firms for projects they do not understand,


\textsuperscript{38}A separate RAND study (Keltner and Finegold, 1994) comparing bank-industry relations in the United States and Germany, revealed that rapid turnover of loan officers in the United States is common. Even if a small business owner connects with a knowledgeable loan officer, the tenure of the loan officer may be just two or three years. In less-specialized banks, a loan officer knowledgeable about a specific industry or firm may be replaced by a loan officer with different interests and expertise or, in some cases, a loan officer unqualified to evaluate small- and medium-sized businesses in any industry. Thus, the relationship developed (often at great cost in time) between a small firm and a financial institution can be shattered by what the financial institution views as a routine change of personnel.
which are beyond the physical control of the borrower. The requirement to carry large work-in-progress inventories is thus shifted to the firms least capable of obtaining economical finance. Small firms face added problems of family succession and inheritance taxes.

Financial Regulation

The federal government and the states impose numerous restrictions on the financial sector in the United States. The regulations support many societal goals: promoting financial stability, preventing the excessive concentration of economic power, reducing fraud, limiting the exposure of deposit insurance funds, providing equal opportunity in lending, encouraging loans to certain types of borrowers, etc. One unintended consequence of these regulations is an increase in the cost of capital to small- and medium-sized businesses. Banking regulations imposed after the collapse of the savings and loan industry, for example, require much more detailed documentation of collateral for secured loans and discourage lending based on the reputation of a company. These regulations increased the costs of processing secured loans and largely stopped banks from giving unsecured loans to small- and medium-sized firms. The documentation required to support an equities issue makes new equity capital beyond the reach of many smaller businesses.

Tax Policies

The U.S. tax code poses additional challenges for capital-intensive firms that have difficulty raising funds for new investments. Capital assets are depreciated over time, so the tax benefits of purchasing a piece of equipment are realized after the costs of purchasing the equipment are incurred—sometimes long after. Because the value of future tax benefits must be discounted, the tax code is biased against the purchase of assets with long depreciation lives, such as machine tools. The problem is exacerbated when the firm cannot finance the outflow of funds before the tax benefits are realized.

A number of proposals have been advanced to alleviate the long-term asset bias in the tax code. The Clinton administration originally proposed restoring the investment tax credit (ITC), which would reduce this bias somewhat. Machine-tool makers would benefit significantly from a restored ITC not only because it would reduce the cost of capital equipment to machine-tool producers, but especially because it would drop the after-tax cost of their product. Figure 4.15 shows how responsive the machine-tool industry has been in the past to changes in the ITC.

The ITC is not without problems, however. Much of the responsiveness of the machine-tool industry to the ITC (and some of the industry's historic volatility) resulted not from the incentive to invest more, but merely from the incentive to invest during a period when the ITC was in effect. Thus, the ITC may have shifted

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39 This provision was deleted from the final 1993 budget in the House Ways and Means Committee.
investment in time much more successfully than it increased total capital investment. The comparative ease of eliminating or changing an ITC increases investor uncertainty.\(^\text{40}\) During the 1960s and 1970s, ITCs were often part of countercyclical economic policies. Because the lead time required to change the tax code and for those changes to influence the economy normally exceeded the ability of economists to accurately forecast future economic conditions, ITC policies were often poorly timed; occasionally, they reinforced the economic cycles they were intended to dampen.

**Comparison to Foreign Practices**

The U.S. machine-tool industry's chief competitors face fewer difficulties in obtaining needed capital. Regulations that restrict bank ownership of equity stakes in firms make relations between banks and borrowers in the United States more distant than they are in other nations. This distance increases the costs to banks of acquiring information about their customers. In Germany, for example, banks often own equity stakes in the companies that they lend to, and interlocking directorships remain a common practice. Much of the financing for the machine-tool firms in Germany comes from a system of local cooperative banks with specialized knowledge about the region's industries. In Japan, industrial keiretsu (persistent alliances of firms) are

\(^{40}\text{Note the numerous policy changes in the 1960s and 1970s shown in Figure 4.15.}\)
normally led and financed by a major bank. Cross-ownership of stock and interlocking directorates are very common. These practices would violate U.S. banking and securities laws and might violate antitrust statutes.

Perhaps most important, each of the United States' main rivals supports investment in advanced industrial equipment, like CNC tools, as part of a broader industrial policy. Whatever the overall efficacy of such policies, they can help specific industries. In all three countries, the machine-tool industry has been a major beneficiary. These benefits are not always directly financial, but often they are. In Italy, for example, the Sabatini Law favors adoption of innovative machinery, providing subsidies and financial aid to users. Japan offers tax credits for investment in many technologies related to the machine-tool industry and grants targeted at SMEs to buy new CNC equipment. Germany provides similar capital and R&D subsidies to small- and medium-sized firms that helped the industry adjust to the new CNC technology.

PRODUCT LIABILITY

For all three critical inputs—technology, skills, and capital—part of the problem the U.S. machine-tool industry faces has been government policy or the lack of it. Machine-tool firms also face a domestic regulatory environment—from environmental controls to health care—that affects many aspects of their operations. A full examination of this regulatory burden was beyond the scope of this study. However, we briefly examined one area of particular concern to machine-tool builders and users: product liability.

The subject of liability provoked stronger passions and more vigorous criticisms of government than any other policy issue in our investigations. Many firms related horror stories: being sued for a machine sold 50 years earlier, even though the users had removed the safety equipment, or being named as a defendant for a machine they never sold because of the word "machinery" in the firm name.

Our focus group participants cited several specific complaints about the current liability system:

- The time and energy necessary to avoid and respond to lawsuits was a disproportionate drain on the resources of small firms, particularly the companies' leadership.
- The wide variation in liability laws among states increased the costs of selling to the national market.

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41 Cases describing the machine-tool industries and government policies in Germany, Italy, and Japan can be found in Appendices A through C.

42 Support might include directed R&D, technological assistance, manpower training, trade policies, etc.

43 A good description of Japanese policies can be found in Agency of Industrial Science and Technology, December 1992.
• The system was perceived to be highly unfair, because a machine-tool builder firm could be sued for a machine it sold years ago, despite modifications by intervening owners.
• Liability insurance is expensive, and the costs fluctuate unpredictably.
• U.S. liability laws raised the cost of doing business more for U.S. firms than their foreign competitors, because of their greater dependence on the U.S. market.
• Liability reduced the machine-tool customer base by forcing certain industries out of business.
• Liability laws led to "defensive" product design.

There is evidence to support some of these views. The number of liability lawsuits filed in federal court against metalworking firms more than doubled from the mid-1970s to mid-1980s (Dungworth, 1988). Data on the costs of such suits and on the larger number of suits filed in state courts are harder to come by. The Association of Manufacturing Technology (AMT) reports that liability insurance premiums increased by a factor of four between 1984 and 1989 and averaged over $235,000 per firm; that, on average, machine-tool firms spend up to seven times more on insurance premiums than on R&D; and that 19 percent of their members do not have product liability insurance, because they cannot afford the premiums. General aviation, a key market for the machine-tool firms in our Wichita focus group, has been hit hard by product liability (Viscusi, 1991; Huber and Litan, 1991, Chapters 12 and 13). While liability laws in the United States apply equally to foreign and domestic manufacturers, it may be easier to sue a U.S. firm, because its assets are here and because no other countries' legal systems are involved. In addition, it is likely that U.S. firms suffer disproportionately from suits over old machines, because the domestic stock of machine tools is, on average, more extensive and older for U.S. than for foreign firms.

Despite the rancor liability causes, however, it is difficult to rank liability alongside the industry's low level of training, poor domestic market, difficulties with exporting, and lag in using new technologies as one of the key causes of the machine tool industry's decline during the 1980s. The differential impact of liability laws on U.S. and foreign firms is also unclear. While the U.S. fatality rate in the manufacturing sector, at 0.022 deaths per 1,000 person-years worked, is twice that of Japan's, it is one-third the rate in Germany (International Labour Office, 1988). When assessing the costs of liability, it is important to remember that product liability is only one of a number of regulatory tools designed to increase worker safety and compensate those who are injured. Competitor nations with different liability laws also have safety regulations, pension systems, and workplace rules that impose different costs on firms. European countries, for example, generally have more comprehensive health care to distribute risks more generally.

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44U.S. manufacturing as a whole averages about 840 deaths and 18,000 amputations annually.
The preponderance of concern among focus group participants was on lawsuits over older or modified machines, rather than on worry that liability would inhibit innovation. Indeed, newer machine tools should be inherently safer than the older ones as their functions become more automated. Lessening the perceived arbitrariness of the system would probably give machine-tool firm executives more time to devote to other aspects of their business but is unlikely to solve many of the industry's basic problems.

DEMAND STIMULUS

Along with inputs and government regulation, domestic demand is one of the key drivers of global competitive advantage (Porter, 1990). This is particularly true in the machine-tool industry, where machine-tool makers are, on average, much smaller, with far more limited research budgets, than the users of their tools. The large machine-tool users have traditionally set the equipment specifications, which in turn have dictated what machines are produced. It was the U.S. Air Force's need for greater precision in metal cutting, for example, that led to the funding and development of NC (see Appendix D; Rendeiro, 1985). The machine-tool industry's continuing dependence on users as a stimulus for innovation was shown earlier in Figure 4.6, which revealed that "customers" were rated the most important source of ideas for new product development by more than 75 percent of all machine-tool makers surveyed.

Declining Metal Consumption

The sharp drop in the demand for machine tools in the United States has put U.S. machine-tool makers at a disadvantage relative to their main competitors. Although this change in demand is certainly influenced by normal economic cycles, the last 15 years have seen U.S. consumption of machine tools fall sharply in real terms and as a share of worldwide demand.

One possible explanation for this decline in demand for machine tools is a shift away from metal consumption. The decline in the importance of metal within the U.S. economy can be seen in Figure 4.16. The drop in metal use has two components. The U.S. economy has shifted away from sectors and industries that use metal, but even among those industries that do use metal, metal use has declined as products have been lightened and other materials, such as plastics and ceramics, have been substituted. The first bar shows actual metal use in 1977. The second bar shows how much metal would have been used in the U.S. economy in 1987 if the economy was simply scaled up from the 1977 economy—i.e., assuming that the rate of metal consumption had kept pace with the rate of economic growth for that decade. The third bar shows how much metal was actually used in 1987.

Although the largest decline in metal use occurred within the troubled U.S. automotive sector, the decline is broadly based. Table 4.1 shows the decline in metal use by industry. The connection between the use of metal in the economy and the demand for machine tools is far from perfect. Most metal used in the economy is not ma-
chined, and advances in other technologies, such as near net shape casting, may significantly reduce the need for machining. Many of the new materials that have been used to replace metal, such as plastics and advanced ceramics, require new forms of machine tools. Although we attempted to include equipment for machining other materials in our expanded definition of machine tools, current statistics do not adequately track tools that machine other materials. Anecdotal evidence suggests this is an important market. For example, one of the oldest and largest U.S. machine-tool firms, Cincinnati Milacron, now derives a much greater portion of its profits from the production of plastic-processing machines than traditional metal-cutting tools and has been far more successful in defending this market from foreign competition (RAND interviews).

Although the decline in metal use within the economy certainly has had an adverse effect on the traditional machine-tool industry, the relationship to the overall economy—and thus the chance for a recovery-driven increase in metal consumption and therefore machine tool purchases—is less clear. While much has been made of the increasing importance of services in the economy at the expense of manufacturing, the decline in metal use is a distinct phenomenon. Figure 4.17 shows that U.S. manufacturing investment held steady or grew slowly during the 1980s. What appears to be happening is a heavy investment in computers and information technology and substitution of newer, higher-technology materials (ceramics, plastics) for traditional metal-processing machines.

Figure 4.16—Declines in Metal Use
Table 4.1
Reduction in Use of Metal by Industry

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor vehicles and equipment</td>
<td>18,196</td>
<td>23,389</td>
<td>12,171</td>
</tr>
<tr>
<td>Heating, plumbing, and structural metal products</td>
<td>12,988</td>
<td>16,704</td>
<td>11,788</td>
</tr>
<tr>
<td>Screw machine products and stampings</td>
<td>9,656</td>
<td>12,418</td>
<td>8,154</td>
</tr>
<tr>
<td>Construction and mining machinery</td>
<td>4,714</td>
<td>6,063</td>
<td>1,865</td>
</tr>
<tr>
<td>New construction</td>
<td>11,576</td>
<td>14,889</td>
<td>10,993</td>
</tr>
<tr>
<td>Other transportation equipment</td>
<td>3,882</td>
<td>4,993</td>
<td>1,570</td>
</tr>
<tr>
<td>Other fabricated metal products</td>
<td>8,660</td>
<td>11,138</td>
<td>7,835</td>
</tr>
<tr>
<td>Metal containers</td>
<td>5,918</td>
<td>7,611</td>
<td>4,613</td>
</tr>
<tr>
<td>Farm and garden machinery</td>
<td>2,414</td>
<td>3,104</td>
<td>942</td>
</tr>
<tr>
<td>Chemicals and selected products</td>
<td>2,121</td>
<td>2,728</td>
<td>624</td>
</tr>
<tr>
<td>Electrical industrial equipment and apparatus</td>
<td>3,704</td>
<td>4,764</td>
<td>2,036</td>
</tr>
<tr>
<td>General industrial machinery and equipment</td>
<td>4,041</td>
<td>5,197</td>
<td>3,372</td>
</tr>
<tr>
<td>Maintenance and repair construction</td>
<td>2,915</td>
<td>3,749</td>
<td>2,032</td>
</tr>
<tr>
<td>Engines and turbines</td>
<td>2,853</td>
<td>3,670</td>
<td>2,209</td>
</tr>
<tr>
<td>Service industry machines</td>
<td>2,838</td>
<td>3,650</td>
<td>2,250</td>
</tr>
<tr>
<td>Metalworking machinery and equipment</td>
<td>2,334</td>
<td>3,002</td>
<td>1,791</td>
</tr>
<tr>
<td>Household appliances</td>
<td>2,156</td>
<td>2,773</td>
<td>1,670</td>
</tr>
<tr>
<td>Materials handling machinery and equipment</td>
<td>1,145</td>
<td>1,472</td>
<td>576</td>
</tr>
<tr>
<td>Miscellaneous manufacturing</td>
<td>2,297</td>
<td>2,554</td>
<td>2,068</td>
</tr>
<tr>
<td>Crude petroleum and natural gas</td>
<td>650</td>
<td>836</td>
<td>0</td>
</tr>
<tr>
<td>Total shown</td>
<td>105,048</td>
<td>135,105</td>
<td>79,359</td>
</tr>
<tr>
<td>Total other</td>
<td>68,823</td>
<td>88,514</td>
<td>53,559</td>
</tr>
<tr>
<td>Total</td>
<td>173,871</td>
<td>223,619</td>
<td>132,918</td>
</tr>
</tbody>
</table>

NOTE: This table shows metal use in 1977, hypothetical metal use in a 1977 economy scaled up to 1987 levels, and actual 1987 metal use.

The Nature of U.S. Demand

Not only the volume of demand, but its nature (e.g., what kinds of tools are purchased) has hindered the ability of machine-tool makers and users to compete in global markets. The nature of U.S. demand was driven by the automotive and aerospace sectors, which were, taken together, the principal and most profitable markets for more than half of all U.S. machine-tool makers (Gordon and Krieger, 1993). After World War II, both of these sectors increasingly demanded customized machines. Defense firms payed premium prices for machines constructed with the most sophisticated technology and materials that had few civilian applications. Automakers required specially designed machines, dedicated to a single function within their mass production systems (Herrigel, 1988).45 These users continued to demand customized, special-purpose tools through the 1970s, while the Japanese

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45According to Herrigel (1988), it was the quantity (large, expanding volume) and nature of demand (dedicated functions, but not custom) from these same customers that enabled the United States to become a world leader in machine-tool production prior to World War II. Machine-tool makers would specialize in a narrow product range that they could then produce in large batches. U.S. automakers were able to demand more-customized machines without developing close, long-term ties to most machine-
Figure 4.17—Manufacturing Investment and Machine-Tool Consumption

were developing a new, more flexible manufacturing system, built around decentralized production in subcontractors with general purpose, CNC machines. In 1983, less than 6 percent of machine tools installed in the United States were numerically controlled (American Machinist, 13th Metalworking Inventory, 1983). Further evidence of the relatively low-technology nature of the U.S. machine-tool market was provided by a 1986 survey of 1,386 metalworking plants (Kelly, 1991, p. 303). It revealed that less than half of the firms had installed even one CNC machine, with small firms less likely to adopt the new technology. In the CNC-using firms, most production workers still operated conventional, nonprogrammable machines. In contrast, two-thirds of small Japanese metalworking firms have at least one CNC tool. Likewise, an international survey of the diffusion of flexible manufacturing systems (two or more CNC machines connected by an automated transfer system) found that, while the United States was the first to introduce a flexible manufacturing system (FMS) in 1965, by 1980 it had only 28 systems installed compared with 71 in Japan (Ehrnberg and Jacobsson, 1991).

U.S. manufacturers belatedly began to emulate the Japanese flexible production strategy in the 1980s, as evidenced by the stock of U.S. CNC tools, which more than doubled between 1983 and 1989, and by the dramatic shift in the machine-tool base toward smaller plants (American Machinist, 1989; Carlsson and Taymaz, 1992a). Many of these plants placed their orders with Japanese machine-tool makers, who

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tool makers by writing their own detailed product specifications and then putting each new order out to competitive vendors.
had already incorporated reliable, relatively inexpensive CNC technology into their tools. The inability of U.S. makers to catch up to Japan's early lead in producing CNC machines is shown clearly in Figure 4.18; perhaps the most striking feature of this comparison is that, in 1991, the percentage of U.S. machine-tool production that was numerically controlled (as measured by the value of tools sold) was still lower than Japan's was in 1979, when CNC was still in its relative infancy. And the United States was the only one of the major machine-tool producers that failed to substantially increase the number of tools it produced in the two most rapidly growing product market segments: CNC machining centers and CNC lathes (Ehrnberg and Jacobsson, 1991).

U.S. machine-tool makers have also been at a disadvantage in making the transition to the new global competitive environment because of their generally weak ties to machine-tool users, as shown in the technology transfer section.

**Procurement**

Government procurement, particularly by the military, has been a significant driver of domestic machine-tool demand. During the 1950s, the U.S. Air Force helped de-

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46The price of NC lathes and machining centers, the two largest and most rapidly growing product markets, actually fell in real terms between 1983 and 1989, while the average price of all tools rose by 47.4 percent (Carlsson and Taymaz, 1992, p. 8).
velop NC technology and accounted for all of the world's demand. Until the mid-1960s, DoD purchases accounted for about 20 percent of the NC market (General Accounting Office, 1974). As in many other industries, the impact of government procurement on the machine-tool industry has decreased substantially since then. About 5 percent of U.S. domestic machine-tool consumption since the mid-1970s has been direct government procurement (Department of Commerce, 1991a, b), although as much as 25 percent of U.S. consumption may be due to indirect government purchases via government contractors (Council on Competitiveness, 1991). Recently, virtually all direct government procurement of machine tools has been by the DoD, up from about one-third in 1983. This government procurement has several effects on the domestic market. Some firms have found a market niche in the government's "Buy American" provisions and thus are able to sell low-end NC lathes and other equipment that is generally the domain of foreign manufacturers (RAND interviews). More importantly, government procurement has helped support the aerospace sector, one of the few segments of the U.S. domestic market that has consistently demanded the high-technology, specialty machines in which U.S. firms are most competitive. While there are few recent examples of the coordinated "technology push, procurement pull" policies that the Air Force pursued for NC systems in the 1950s, DoD procurement has in recent years helped spur the development of new technologies, such as the ribbon-laying machines used in manufacturing composite structures for aircraft, in which the United States still excels.

POOR U.S. EXPORT INFRASTRUCTURE

With the long-term decline in domestic demand, the failure of most U.S. machine-tool makers to focus on the global market has become a major problem for the industry. As described in Chapter Three, the primary locus of machine-tool consumption has moved away from the United States to Europe and the Pacific Rim. Exports have therefore become vital. Only they can provide U.S. machine-tool makers with the growth, profits, and economies of scale and scope needed to achieve and maintain competitiveness. If the U.S. machine-tool industry continues to treat overseas markets as residual outlets for surplus production, it will continue to fall behind the export-oriented Asian and European industries that dominate world markets. This section examines the composition of increasing foreign demand, outlines U.S. export performance, and considers some reasons for the U.S. machine-tool industry's consistent failure to compete effectively in foreign markets.

During the 1980s, a structural shift in world machine-tool demand caused the majority of machine-tool consumption to shift away from the United States. In 1980, the real value of world consumption was at a five-year high, and the United States accounted for the largest single share of that consumption. In the following few years, a harsh global recession led to a major drop in world and U.S. machine-tool consumption, but the United States maintained a consistent (large) share of world consumption. Between 1984 and 1990, however, when U.S. machine-tool consumption stabilized at depressed levels, world consumption of machine tools doubled in real
value. As Figure 4.19 indicates, Germany and Japan then became the two largest sources of world demand for machine tools.\textsuperscript{47}

A closer examination of the current structure of the world machine-tool market shows that the importance of markets outside the United States continues to grow. The Japanese and German machine-tool markets, which showed enormous growth during the 1980s, were the largest national machine-tool consumers in the world, at $8.3 billion and $6.7 billion respectively in 1991. Led by these nations, Europe and the Pacific Rim have become the dominant regions for machine-tool sales. The European Union, accounting for 34 percent of world consumption, is the largest single integrated machine-tool market in the world; the Pacific Rim is the fastest growing regional market. Total machine-tool consumption in China, Taiwan, and South Korea, for example, increased 25 percent between 1987 and 1991, from $2.42 billion to $3.03 billion.\textsuperscript{48}

The U.S. machine-tool industry has not yet adapted to this enormous shift in global demand. Throughout its recent history, the U.S. machine-tool industry has not been a significant player in export markets.\textsuperscript{49} In the mid-1970s, when the U.S. machine-

![Figure 4.19—World Machine-Tool Consumption, 1976–1991](image)

\begin{flushleft}
\textsuperscript{47}The deep recessions in Japan and Germany have closed the gap between the United States and its main rivals in 1991 through 1993 (see next chapter).

\textsuperscript{48}The machine-tool market in the former Soviet Union, once estimated to be the largest in the world, has been declining rapidly since 1989.

\textsuperscript{49}The large U.S. machine tool makers made substantial direct investments in Europe in the postwar period, but failed to capitalize on these investments when European demand grew in the 1980s.
\end{flushleft}
tool industry was the strongest in the world, U.S. machine-tools makers satisfied just under 5 percent of foreign machine-tool consumption. This trend continued in the 1980s, when the lion's share of global machine-tool consumption moved offshore. As Figure 4.20 indicates, U.S. exports during the last decade have not increased to keep pace with the large increases in non-U.S. world consumption. Between 1986 and 1991, while the nominal annual value of U.S. exports increased from $409 million to $908 million, a 124 percent increase, the U.S. share of non-U.S. world consumption fell from 2.81 percent to 2.46 percent.

American machine tools have also performed poorly in the world's largest individual markets (see Figure 4.21). In 1991, the United States held just over 1 percent of the Japanese market. While this market share in Japan compares favorably with that of other foreign competitors, it remains a consistent source of consternation among U.S. producers, particularly the large, established, export-oriented firms (see discussion below). U.S. machine tools have also fared poorly in Europe, where markets are substantially more accessible. The German and Italian markets, the two largest in Europe, import over 30 percent of their machine tools. The United States, however, has been unable to gain even 2 percent of these markets. The same has been true in France, which imports over 70 percent of its machine tools. The leading markets for U.S. machine-tool exports are the ones nearest to hand: Canada and Mexico. In 1992, these two small markets accounted for one-third of U.S. exports.

The U.S. export record stands in contrast to the leading machine-tool nations in the world, particularly Japan. Between 1976 and 1991, Japan consistently exported a

![Graph showing U.S. Share of Non-U.S. World Consumption, 1976–1991](Figure 4.20)

**Source:** AMT (1993).
high percentage of its machine-tool production, averaging 39 percent throughout the period, compared with a U.S. average of under 30 percent. Of the leading world machine-tool exporters, only Germany exports a higher percentage of production than does Japan.\textsuperscript{50} A large share of German exports, however, is within the European Union (EU), where German machines receive better tariff treatment than machines exported from non-EU nations.

\textbf{Low Export Orientation}

The main factor behind the poor U.S. export performance has been the consistent lack of export orientation among most U.S. machine-tool firms. As the largest consumer of machine tools in the world throughout most of the postwar period, the United States had little incentive to export on a large scale—the large captive demand for machine tools in the United States was more than sufficient to keep U.S. production running near full capacity. Large U.S. firms often served overseas markets through foreign subsidiaries, but failed to integrate these operations into a global strategy. During the 1960s and 1970s, U.S. machine-tool builders exported primarily when cyclical lulls in domestic demand caused short-term declines in

\textsuperscript{50} Smaller countries, such as Switzerland, export an even higher percentage of total production.
sales. When domestic demand would pick up again, U.S. firms would often neglect export markets, filling U.S. orders first.\textsuperscript{51}

This failure to focus on foreign markets left the U.S. machine-tool industry ill-equipped to meet the challenges of increasingly global machine-tool competition. This is particularly true for the many small U.S. machine-tool makers, most of which lack the resources and knowledge to compete effectively in world markets. Exporting requires extensive knowledge of other countries and strong relationships with foreign customers. Fostering these relationships requires knowledgeable sales personnel and, most important, prompt technical support, which few U.S. firms have routinely provided to their export customers. Only a handful of large, established firms in the United States have devoted resources to moving up the export "learning curve."

**Weak Export Support**

Many of the small U.S. machine-tool firms would find export sales more attainable if they had access to greater institutional support in the form of industry trade association collaborative programs or government initiatives designed to educate and assist prospective exporters. Unlike other countries, however, the United States provides little institutional support for machine-tool exports (see Appendices A through C). The federal government offers little or no guidance and is widely distrusted by industry representatives (RAND focus groups). Export promotion programs have started to materialize in state and local governments and at AMT, the machine-tool trade association in Washington, but they have not yet strongly improved the ability of small U.S. firms to export. This is in sharp contrast to Germany and Japan, where strong trade associations and other organizations directly assist firms with exports, customer relations, and regulatory procedures, and where governments have actively promoted machine-tool exports.\textsuperscript{52}

**Strong Export Controls**

Several other factors play significant roles in explaining the poor U.S. export performance over the last decade. Perhaps the most important external obstacle to exports has been the export control regime enforced in the United States. In interviews and focus groups conducted for this study, U.S. machine-tool builders and distributors repeatedly cited export controls as a major impediment to increasing foreign sales. The problems of U.S. machine-tool builders in this area stem from strict regulations, enforced by a decentralized, uncoordinated interagency bureaucracy.

\textsuperscript{51}For example, the United States had a strong position in the Swedish machine-tool market, but withdrew in the 1970s when U.S. orders began to exceed U.S. production capacity. When domestic demand slackened and U.S. firms returned to Sweden, other European machine-tool builders had gained control of the Swedish market (see Magaziner and Patinkin, 1989).

\textsuperscript{52}In Germany, the machine-tool trade association, the VDMA, has established a regional demonstration center in Singapore to serve as a base for German machine-tool sales to Pacific Rim countries, while regional governments and chambers of commerce provide a wide array of export services for SMEs.
Some evidence supports the claim that export controls present a more difficult obstacle for U.S. firms than for their competitors abroad. The principal determinant of export control in most of the Western world has been the Coordinating Committee on Multilateral Export Controls (COCOM), a multilateral organization originally conceived to limit export of defense-related technology to the communist world during the Cold War. While COCOM was officially disbanded in March 1994, its regulatory regime remains in force to limit proliferation of the same defense-related items to potentially hostile nations and the Third World. Japan, Germany, and most other industrialized Western nations have limited their export controls to those outlined by the COCOM commodity control list, but the United States has traditionally imposed additional proscriptions on exports through a series of export administration acts.

A close examination of export values to China and the former Eastern Bloc provides mixed evidence on the differential enforcement of export controls. Germany exported far more machine tools to the Soviet Union during the 1980s than did other Western nations (see Figure 4.22). In 1983, with world machine-tool consumption in

![Graph showing export values](image)

**Figure 4.22—U.S.-German Export Gap and Exports to USSR**

53 A replacement to COCOM is expected in the fall of 1994. How strictly the rules are enforced may vary by country and product. The United States, for example, is now easing export restrictions on some items to Russia.

54 We have no systematic evidence that demonstrates that export controls explain Japanese success in the Chinese market and German success in the Warsaw Pact. Proximity and history may also be important. Nevertheless, the notable performance of our competitors in these restricted markets, coupled with anecdotal evidence of differing interpretations of export controls, strongly suggests that U.S. firms have been placed at a disadvantage in selling to these nations.
a state of major decline, German sales to the Soviet Union increased, accounting for approximately 50 percent of total German exports. Access to the Soviet machine-tool market helped to cushion German machine-tool makers from the effects of declining global demand. Likewise, Japan sold significant quantities of machine tools to China, while other Western nations exported only nominal amounts, in the mid-1980s (see Figure 4.23). Japanese machine-tool sales in China have declined substantially in recent years, and the United States is now the leading exporter to China.55

Perhaps the most detrimental effect of the U.S. export control regime, however, has been the difficulty it has created in exporting machine tools anywhere in the world. The system set up to limit certain “high-tech” exports, including CNC machine tools, to specified countries indirectly deterred U.S. machine-tool exports by creating time-consuming, unpredictable export-licensing procedures. Every machine tool exported by a U.S. firm, regardless of its sophistication or destination, requires an export license from the federal government. Because the licensing process can take six to nine months, U.S. machine-tool firms often do not bother to apply for licenses, since the sale in question may be taken by foreign producers that require less time to get government approval. While the government attempted to streamline export

Figure 4.23—Selected Country Exports to China, 1987–1991

55Anecdotal evidence suggests that many Chinese firms still harbor deep resentment against Japan and would prefer to purchase U.S. tools if they were available.
licensing procedures for machine tools in the late 1980s, almost every machine-tool builder interviewed for this study continues to experience major difficulties in procuring export licenses. One of the leading U.S. producers of CNC milling machines, for example, participated for a full year in a U.S.-government sponsored initiative to sell materials related to the manufacture of aircraft parts to the People's Republic of China, only to have the DoD block the sale at the last minute, after it was determined that this firm's contribution to the sales, several five-axis milling machines, was prohibited for foreign sale by U.S. export controls.

Other Possible Barriers to Export

Export Financing. The inability of U.S. machine-tool firms to procure reliable export finance presents another impediment to aggressive machine-tool export. Banks and other financial institutions often consider the financing of export sales by machine-tool firms to be unacceptably risky. They are wary of lending based on a promise of repayment by a foreign customer who is not covered by U.S. financial laws and regulations. Most government-sponsored export finance is largely unavailable to small machine-tool firms, and what is available is difficult to obtain. The U.S. Export-Import Bank imposes a minimum loan amount on its borrowers that exceeds the amount that most machine-tool firms can assume. This combination of factors makes it difficult for U.S. firms to procure export finance.

Trade Barriers. Finally, various trade barriers restricting imports in foreign countries create a further impediment to U.S. machine-tool exports. In the developing world, where manufacturing industries remain largely protected from imports, machine tools are often subject to high tariffs. In industrialized countries, however, tariffs on all major categories of machine tools are virtually nonexistent.\textsuperscript{56} In these countries, so-called “nontariff barriers” (NTBs), such as local standards or high distribution costs, account for whatever trade protection may exist. In Europe, these types of trade barriers appear to be negligible for machine tools, as several non-European nations have succeeded in gaining substantial sales. In Japan, however, machine-tool exporters claim that NTBs of various sorts impede sales, essentially shutting out foreign competition.

The Case of Japan. In the last decade, Japan has replaced the United States as the world's leading producer of machine tools. Perhaps the most direct causal factor for the Japanese rise to machine-tool dominance is the enormous growth in the domestic Japanese machine-tool market. Between 1977 and 1990, Japanese machine-tool consumption tripled in real value. Despite the impressive size of the Japanese machine-tool market, it remains the world's most difficult market for export sales. Throughout the 1980s, an era of increasing machine-tool demand, import penetration into the Japanese market remained stable and remarkably small by international standards, fluctuating between 7 percent and 10 percent since 1976 (see Figure 4.24).

\textsuperscript{56}The United States, as noted earlier, imposed VRAs on some categories of Japanese and Taiwanese tools from 1987 to 1993. Some interviewees suggested that Europe has maintained informal VRAs on Japanese machine-tool imports, but we were unable to confirm their existence.
Although the real value of Japanese imports grew somewhat in the latter half of the 1980s, much of this is attributable to the rise of the yen (see Figure 4.25). This presents a stark contrast to the U.S. and German markets. In the United States over the same period, declining demand was coupled with declining domestic market share. In Germany, impressive market growth was accompanied by steadily increasing import penetration.

Individual countries’ shares of the Japanese market have also remained remarkably consistent (see Figure 4.26). Italy, Taiwan, Switzerland, and the United States hold small but steady shares of the Japanese market, suggesting that individual producers in these countries may be successful in highly specialized niche markets in Japan. The one exception here is Germany, whose market share has fluctuated from year to year. This is probably attributable to the high-value, high-priced nature of German production, which, especially with limited sales, allows changes in the volume of sales to substantially change total sales value.

Why does the Japanese market continue to show consistently low import penetration? Japan has a well-established postwar history of protection for “infant” industries, of which the machine-tool industry was a prime example. In the 1960s, MITI explicitly shielded the Japanese machine-tool industry by prohibiting foreign direct investment in the machine-tool sector. During this era, MITI encouraged foreign firms, particularly U.S. firms, to license machine-tool technology to Japanese firms seeking to become competitive in machine-tool production. In 1969 and 1970, for
Figure 4.25—Real Values of Imports: Japan, Germany, and United States, 1976–1991

Figure 4.26—Leading Country Shares of the Japanese Machine-Tool Market
example, 12 licensing agreements between Japanese machine-tool firms and foreign firms were completed (nine with the United States), all covering state-of-the-art NC technology (Holland, 1989, p. 127). The inflow of technology included the license of servoscontrol technology from U.S.-owned Gettys (a leading maker of CNC controls, based in Wisconsin) that enabled FANUC to create its own CNC control; this, combined with high tariff protection and the absence of foreign firms in Japan, contributed to the maturation of the Japanese machine-tool industry until it became internationally competitive in the 1970s. Only then did impediments to foreign direct investment in machine-tool manufacturing and tariff barriers begin to come down in Japan.

The effects of this long-standing policy continue today in the Japanese market. Recent research by Penubarti (1993) demonstrates that Japan’s markets are relatively closed to imports and that the sector where this gap in imports from the United States is largest is nonelectrical machinery, which includes machine tools. While explicit trade barriers, such as high tariffs and import quotas, have been removed, several factors impede foreign sales of machine tools in Japan. Foremost is the presence of what are now the world’s most productive large machine-tool makers. Many years of trade protection have allowed Japanese machine-tool firms to foster very close ties with their domestic customers. The inability of foreign suppliers to build strong relationships with Japanese machine-tool customers appears to be a strong structural factor that impedes growth in import sales in Japan. The keiretsu system of close vertical relationships between some Japanese producers and consumers of machine tools is another barrier that is difficult for foreign firms to penetrate. The language difficulties of foreign sellers and high distribution costs for imported goods also explain part of the problem.

Several U.S. machine-tool builders indicated during the course of this investigation that selling to Japan, while possible, requires a larger investment of time and money than they are willing to make. The rules of the market are difficult to master, and the potential payoffs appear distant and uncertain, especially now that a fiercely competitive domestic industry is fighting for sales in the face of declining consumption. One of the leading U.S. producers of CNC machining centers described Japan as “more trouble than it’s worth.” Another stated simply, “There has to be an easier way to make a buck.” The existence of low import penetration into the Japanese market, therefore, is not explainable by one single factor—it involves a number of factors, most of which are difficult for governments to address.

57 He builds an economic model that predicts imports and exports in the 30 largest traded sectors assuming free trade, then compares this with actual trade figures for 14 countries. This shows that Japan imports less than it would under free trade from almost all countries. In 26 of 30 product segments, it imports less than expected from the United States, with tobacco and oil/coal the only exceptions.

58 This close vertical relationship extends to Japanese transplants in the United States and other foreign countries.
THE DECLINE OF THE FRENCH MACHINE-TOOL INDUSTRY

The structural factors discussed in this chapter have been shown to be highly related to the decline of the U.S. machine-tool industry relative to Japan, Germany, and Italy in the new global competitive environment. Confirmation of the importance of this set of factors in explaining competitive advantage in machine tools is provided by the case of France. The French machine-tool industry experienced an even more severe decline than did that of the United States in the early 1980s, with employment dropping from 27,000 to 11,000 and production declining by 60 percent between 1980 and 1992. As in the United States, it was Japanese makers of commodity CNC tools that seized the French market, eventually claiming 76 percent of all sales.

Research on the French machine-tool industry (Maurice and Sorge, 1993; Ziegler, 1989) indicates that it suffered from very similar problems to that of the United States: an industry composed primarily of small, isolated machine-tool firms, which had few export markets outside Europe; heavy reliance on sales of customized machines for the domestic automotive and defense sectors, users who were slow to make the adjustment from NC to CNC tools; an absence of cooperative links between machine-tool makers, suppliers, and users; a dearth of high-quality apprentices and few benefits from the elite universities, which had an arm’s-length relation with industry and lacked an applied research focus; and distant ties with the French state, which concentrated its technology policy on large-scale projects, such as nuclear power, Airbus, and Minitel.

The French case also indicates that attempts to address one factor in isolation are unlikely to remedy the problem, as the government’s belated attempts to create economies of scale by forming a large, state-owned machine-tool firm did not succeed in restoring the competitiveness of the French machine-tool industry.

STRUCTURAL CHALLENGES TO THE INDUSTRY

In summary, the basis of competition for the machine-tool industry worldwide has changed substantially over the last 15 years. Product life cycles are much shorter; newer technologies have been added than the traditional mechanical ones; system integration is becoming central to success; global competition is increasing; higher skills are required; access to capital has become even more vital; and external relationships are exceedingly important.

A systematic examination of the seven structural factors that determine competitive advantage in this global market reveals a number of important challenges. The following are among the most important:

- Most U.S. machine-tool firms are small, so cooperation is essential—but geographic dispersion and a tradition of independence make it difficult.
- Poor links to customers and to publicly funded research programs handicap U.S. machine-tool makers’ technology development and transfer.
• Poor entry-level qualifications and barriers to in-firm training have resulted in low skill levels among the makers and users of machine tools, lowering their productivity and capacity for innovation.

• Difficulty obtaining capital, both for investing in new equipment and for financing sales, has hindered the growth of U.S. machine-tool makers.

• The U.S. industry's traditional reliance on domestic demand—which has not only declined in volume but also differs in kind from the larger international market—has substantially limited its ability to compete with foreign firms both domestically and abroad.

• Although pursuing the export market seems critical to success, the U.S. industry faces several barriers: its own domestic orientation, weak export supports, strong export controls, and nontariff trade barriers in the vital Japanese market.
CURRENT MARKET OVERVIEW

As we have seen, the U.S. machine tool industry suffered a dramatic decline in the early 1980s and failed to recover for the rest of the decade. The industry continued to close plants and shed employees in the 1990–1992 recession, with metal-cutting firms the hardest hit (see Figure 5.1).

In the last year, however, there has been a reversal in the fortunes of the U.S. machine-tool industry (see Figure 5.2). In this productivity-led recovery, U.S. man-

![Graph showing changes in number of plants and employees per category.](image)

**Figure 5.1—U.S. Machine-Tool Industry Shed Plants and Jobs in the 1990–1992 Recession**

SOURCE: Dunn and Bradstreet.
NOTE: These data record significantly more establishments than the previous counts of machine-tool makers.
Manufacturers began by adding machines rather than workers, increasing general capital spending by 16.2 percent in 1993, and increasing machine-tool orders by 25 percent to $3.78 billion (AMT, 1994). This has generated large profits and filled order books for many U.S. machine-tool makers. According to the Commerce Department, the machine-tool industry was the most rapidly growing sector of U.S. manufacturing in early 1994 (Nauss, 1994).

The resurgence of the U.S. machine-tool industry looks likely to continue in the near term as U.S. manufacturers replace an aging capital stock. The average age of installed metalworking equipment is 10 years, the oldest since World War II, this at a time when advances in the capabilities of machines are more rapid than ever before.

Yet it is still too early to tell whether the recent improvement represents a cyclical blip or the start of a long-term recovery for the U.S. machine-tool industry. There are a number of reasons for treating this resurgence with caution:

1. As our research has shown, U.S. machine-tool makers' fortunes have always been tied closely to the domestic market, and thus it is not surprising that they should expand when U.S. demand for machine tools is growing rapidly.²

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¹Analysts are predicting a 13-percent increase in capital spending in 1994 (Nauss, 1994).
²The single largest customer for machine tools—the automotive sector—has tended to replenish its capital stock every 10 years. The current surge in demand fits with this cycle.
2. The U.S. machine-tool industry looked especially healthy in 1993–1994 because its main rivals in Germany and Japan were still in the midst of severe economic crises. (The next section of this chapter provides more detail on the crises in the German and Japanese machine-tool industries.)

3. The industry's growth is occurring off a much diminished base, with U.S. output and orders still less than half their 1980 peak.

4. Growth has been most substantial at the low end of the U.S. market, which caters primarily to price-sensitive job shops. This demand can be met with machines produced by Taiwan, South Korea, and Spain and may soon be within reach of China and the former communist bloc countries in eastern Europe. Given the lower skills required to produce these simpler machines and the wage differentials between the United States and these nations, it is difficult to see how U.S. manufacturers could create a sustainable competitive advantage in commodity machine tools.

5. There are signs that the same pattern that marked the beginning of the 1980s decline for machine tools is recurring: a recession followed by a rapid surge in demand that U.S. machine-tool builders do not have the capacity to meet, thereby allowing imports to win a larger share of the U.S. market, as shown in Figures 5.3 and 5.4. Said one rapidly growing U.S. maker of vertical machine centers: "I'm turning away orders almost every day. We've nearly doubled capacity and I still can't meet the demand. Customers are buying from anyone who can deliver the machines now" (RAND interviews).

Figure 5.3—Recent U.S. Machine-Tool Trade Balance
Figure 5.4—Recent U.S. Imports of Machine Tools

6. Despite significant initiatives, the underlying structural weaknesses (analyzed in Chapter 4) have not yet been solved and may continue to deter long-run expansion.

Counterbalancing these cautions about the current recovery are several factors that suggest that the U.S. machine-tool industry is now better positioned to compete successfully in the long term. First, in response to the problems of the last decade, many American machine-tool firms have already restructured. The downsizing of the industry drove many of the weaker firms out of the business, leaving a core of machine-tool producers better capable of competing. For example, since Gidding & Lewis bought out Cross & Trecker in 1991 to become the United States' largest machine-tool maker, it has rationalized the organization leading to a near doubling of productivity, while expanding sales and profits (Nauss, 1994). Coupled with productivity improvements, the significant fall in the value of the dollar has made the United States a low-cost manufacturing location relative to Japan and Europe. The variety of successful approaches being pursued by U.S.-based firms is illustrated in the Strategies for Competitiveness section of this chapter.

In addition, our research indicates that the United States holds a firm lead in many technologies that will become increasingly important for machine tools and is at least competitive in most others. In the critical area of controllers, for example, technology would appear to be weakening the grip of FANUC. Smaller, PC-based controllers, an area in which FANUC does not enjoy the overwhelming advantages that it does with its dedicated controllers, offer increased flexibility and advanced user interfaces and are poised to capture larger portions of the controller market (see
Appendix D). Since the pace of technological innovation is continuing to increase in this industry, the U.S. lead in R&D could translate into a national competitive advantage if the right mechanisms are put in place to move the results of this research onto the shopfloor.

In the remainder of this chapter, we first contrast the current market conditions in Germany and Japan with the boom underway in the United States and then look at the strategies and technologies that U.S. machine-tool makers may be able to use to reestablish their competitive position.

CRISIS FOR COMPETITORS

The continuing deep recession in Japan and Germany is a double-edged sword for the United States: The recession is forcing restructuring in those nations' machine-tool industries, giving American firms an opportunity to gain in global markets. At the same time, however, it is creating strong incentives for Japanese and German machine-tool companies to export, to make up for slack demand at home, and the expanding U.S. market is one of their prime targets.

Recession in Europe's Machine-Tool Market

The current recession in Europe is deep, with machine-tool leader Germany particularly hard hit (for more details, see Appendix B). As shown in Figure 5.5, German
machine-tool makers experienced drops of over 20 percent in orders in each of 1991 and 1992. Not shown is the staggering 52-percent drop they suffered in the first quarter of 1993. Sales of general machinery have dropped to one-third of their 1989 values and have forced many German machine-tool firms into restructuring or bankruptcy.

Adding to Germany's troubles, the slow, costly process of reunification has eroded investor confidence, which has a marked effect on machine-tool firms. Likewise, the hoped-for investment boom in eastern Europe and Russia has not materialized. Instead, the economic turmoil in these countries has resulted in a sharp drop in what was one of Germany's largest and most profitable markets. Finally, and perhaps most worrisome for the Europeans, the Japanese have begun an aggressive campaign of exports to Europe. There are reports of stringent cost cutting of Japanese machine-tools, including two-for-one deals on machines, and increased pressure on distributors to unload inventories, even if they are forced to take a loss.\(^3\)

Like the Japanese foray into the U.S. market in the early 1980s, this export drive appears to be showing a real structural weakness in the German machine-tool industry. The high cost of labor and low working hours are causing many German manufacturers, including machine-tool firms, to consider moving abroad. As shown in Figure 5.6, Japanese firms, particularly the volume producers of commodity-type machine tools, are far more efficient in the production of machine tools than their German

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\(^3\)Interviews with European government officials and machine-tool makers.
counterparts. As would be expected from such glaring productivity differences, German volume producers, such as Maho, Gildemeister, and Deckel, have experienced trouble in competing with large Japanese machine-tool makers, while specialty producers, such as Trumpf, remain competitive.

**Parallel Problems In Japan**

The Japanese are also experiencing a severe recession and, hence, a sharp downturn in machine-tool orders and industrial investment more generally, as shown in Figure 5.7. Demand for machine tools in 1992 was only about half the 1990 level and continued to fall in 1993, with orders estimated to be down another 30 percent. Some anticipate that it will be the end of this decade before domestic orders reach the 1990 level again. This collapse of domestic demand has caused Japanese firms to push even more aggressively in export markets.

In the past, Japanese firms have been able to weather cyclical crises (see Appendix A). Debate raged in Japan following the yen’s rapid appreciation in the mid-1980s as to what Japanese firms could do to remain competitive in global markets. Exemplifying their long-term perspective, machine-tool firms maintained prices in real terms to keep their market share and thus put a pinch on profits. This trend is evident in movements of the export price index for machining centers shown in Figure 5.8. In fact, while firms would be expected to raise export prices with the value of the yen to maintain receipts, they actually lowered prices dramatically.

![Figure 5.7—Downturn in Japanese Machine-Tool Market](image)

**SOURCES:** Production, MITI; Investment, Economic Planning Agency.
This time, however, the Japanese industry may not be able to make such sacrifices for the sake of market share. According to several industry participants, Japan's current recession has been the most deleterious to the industry since the war. Debate continues to rage in Japan on the extent of overinvestment during the late-1980s boom. In an effort to preserve their lifetime employment system despite the major decline in orders, leading machine-tool makers have eliminated all nonpermanent workers, reduced hiring and R&D, and shifted personnel from production into sales, maintenance, and refurbishing operations. Firms have also shifted much of their formerly subcontracted work in house, creating further pressures on the extensive network of suppliers. The continuing difficulties they face in restructuring, however, were highlighted in early 1994 when the president of Okuma, one of the leading machine-tool makers, was forced to resign; he had attempted to cut labor costs by lowering the firm's retirement age from 60 to 56, contradicting government policy that encourages late retirement because of Japan's aging population.

These current difficulties in Europe and Japan clearly create some opportunities for U.S. firms. What is not possible to determine at this stage is whether these opportunities are merely temporary outgrowths of the business cycle or whether they represent longer-term realignments in the world machine-tool industry.

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4Interviews with Japanese machine-tool manufacturers.
5This illustrates the powerful influence that the Japanese government continues to have over firms. "Root or Branch?" *The Economist*, February 26, 1994, p. 54.
STRATEGIES FOR COMPETITIVENESS

As noted at the outset, there is a wide diversity of product markets and firm types within the U.S. machine-tool industry. While the industry as a whole declined significantly over the last decade, some firms continued to prosper. Others have now restructured to meet market and import challenges, while several start-ups have found profitable market niches. In this section, we examine different ways in which U.S.-based firms have coped with the changing competitive conditions. While neither the list of strategies nor the roster of firms is comprehensive, we believe it represents the gamut of approaches being pursued in the United States today.

We begin with companies that focus on high-technology or custom-designed machines: Ingersoll Milling Machine Company, Trumpf Industries, and Perceptron. We then examine firms with more diversified product lines, often producing midlevel commodity machine tools, such as horizontal and vertical machining centers: Cincinnati Milacron, Mazak Corporation, and Hurco Companies, Inc. Finally, we conclude with smaller firms that concentrate on lower-end commodity CNC machines: Fadal Engineering Company and Haas Automation, Inc.

Ingersoll Milling Machine Company: Working with the Customer and Taking the Long View

Ingersoll Milling Machine Company is the second-largest machine-tool manufacturer in the United States, posting $460 million in sales in 1991. It is an international manufacturer of transfer machines, often called station-type machines. The company, part of Ingersoll International, Inc., designs and manufactures special-purpose metal-cutting and automated metal parts machining systems in the United States, Germany, and the United Kingdom (see Appendix E for a detailed case study of Ingersoll). Ingersoll is a major supplier of machine tools and manufacturing systems to the aerospace, automotive, farm, truck, and tractor industries. It also supplies the power generation industry and the primary metals industry. Ingersoll is regarded by automakers as particularly strong in developing systems for the manufacture of engine blocks, pistons, and body dies. Its main competitors in the U.S. market are Giddings & Lewis, Lamb Technicon, and Tri-Way. Ingersoll is a profitable company and is held in high regard throughout the machine-tool industry.

Ingersoll succeeds by tailoring products to its customers' needs. The nature of the transfer machine business typically requires close relationships with machine-tool users, and Ingersoll often custom-designs machines in collaboration with customers. Ingersoll has worked assiduously to nurture these relationships, even building factories and service centers close to major customers. For example, the company expanded its Troy, Michigan, operation to allow Ingersoll engineers to participate in "before- and after-build" continuous improvements for U.S. automakers, sometimes rebuilding machines made by other manufacturers. Ingersoll also maintains facilities near its customers in Germany and the United Kingdom for similar purposes.

Ingersoll is able to respond to customers' needs by maintaining a state-of-the-art manufacturing capability that concentrates on flexibility. Ingersoll has always been
quick to implement the latest technology; it was one of the first private companies to install NC drills (in 1957), adopted an automatic guided-vehicle system in the early 1970s, purchased an NC machining center and CAD system in 1975, and was one of the first machine-tool firms to win an award under the Advanced Technology Program (see Chapter Six).  

Ingersoll is family owned, and this, according to company representatives, allows the firm to take the long view toward investments and product markets. For example, Ingersoll established its German subsidiary in 1961 and had to wait 25 years for it to yield a return. Ingersoll has also been one of the few U.S. machine-tool makers to operate successfully in Japan.

Trumpf Industries: Bargain-Basement High Technology

Trumpf Group is one of the world’s largest and most sophisticated machine-tool makers. Headquartered in Germany, Trumpf Group is composed of 26 subsidiaries in 14 countries. It entered the U.S. market in the 1970s when it purchased a small firm that had developed a laser for cutting metal. It subsequently bought another U.S. company and merged them to form Trumpf Industries, with sales of $38.7 million in 1991.

Over time, Trumpf became increasingly dissatisfied with the quality and reliability of the laser it had purchased from the U.S. firm and took the problem to a German Fraunhofer Institute, which helped it develop a new product. This high-end laser cutting tool was a success in Europe, but had only limited sales in the United States because of its price. Trumpf redesigned the machine for the U.S. market, cutting the price by more than $100,000 by removing one axis and reducing the capabilities by about 10 percent. The new strategy was a success, enabling Trumpf to capture roughly one-quarter of the U.S. laser cutting market and increase sales by 30 percent in 1992 despite the overall decrease in U.S. machine-tool demand.

Trumpf has also had to adapt its human resource and production strategy to the U.S. context. The 240 workers in its Connecticut facility are less productive on an hourly basis than their higher-skilled German counterparts, but they are also cheaper and work longer hours (300 to 400 hours per year more than in Germany). Trumpf has tried to compensate for the lack of a U.S. apprenticeship system by hiring skilled immigrants from Eastern Europe. It has also faced difficulty finding engineers with practical experience, so it has designed a one-year accelerated apprenticeship program for its new engineering graduates.

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6 In recognition of leadership in manufacturing, Ingersoll was given the 1982 Leadership and Excellence in the Application and Development of Computer Integrated Manufacturing Award by the Society of Manufacturing Engineers.
Perceptron: Investing in High Technology

Perceptron is an example of a company whose business is based upon high technology. It is a small public company headquartered in Farmington Hills, Michigan, employing 70 people worldwide. Annual sales are growing rapidly, from roughly $13 million in 1992 to a projected $20.7 million in 1994. Its primary product is optical sensing systems, mainly for dimensional measurement applications in the automotive industry that require submillimeter (e.g., 0.1 mm) accuracy. It takes 15 seconds for this automated scanning process to detect if any part is out of position, instead of the hours manual inspection would require.

The laser-based, optical-sensing technology used by Perceptron was developed at the Environmental Research Institute of Michigan (ERIM), a not-for-profit corporation located in Ann Arbor, Michigan, and was commercialized by Perceptron. The systems, which cost an average of $1.8 million, are highly automated, taking data generated by the sensors and converting them into useful forms for graphical outputs, operator displays, management reports, process control inputs, etc. Perceptron also sets up and calibrates its sensor systems, supports data processing software, and trains users. The company has no direct rivals for its product and has established sales offices in Germany and Japan.

Perceptron is an example of how local cooperative networks can help a small firm compete globally. Although it allocates only 1 percent of its gross annual sales to R&D, it attempts to leverage this investment to the maximum extent by working with others on R&D and focuses its internal efforts on commercializing technology. The company is an active member of the NSF-sponsored Industry-University Cooperative Research Center for Dimensional Measurement and Control at the University of Michigan and was in fact instrumental in helping to establish the center.

Cincinnati Milacron: Diversification and Team Design

Whereas Ingersoll represents a successful company with a consistent strategy pursued over decades, Cincinnati Milacron is a company with a new strategy designed to bring it back to consistent profitability. Milacron was established in the late 1800s and is the third-largest machine-tool builder in the United States (sales of $384 million in 1991), behind Giddings & Lewis and Ingersoll. It is a much larger company than Ingersoll if non-machine-tool products are counted. Milacron is divided into three divisions that provide roughly equal portions of sales: machine tools, plastics machinery, and industrial products. Milacron employs 9,000 people worldwide, and total sales in 1993 are projected to be $1.1 billion. Although the majority of manufacturing sites are in the United States, other plants are in Canada, Europe, Japan, and Mexico. The machine-tool division has a diversified product line featuring advanced machine tools, aerospace machine tools, standard machine tools, manufacturing systems, applied machines, controllers, and tape-laying machines for aerospace applications. Milacron dropped its robotics and laser machining departments in 1990. While Milacron depends on the development of technology to remain competitive in a number of areas, the firm’s strategic focus centers on diversification away from
metal-cutting and forming machines. It has also embarked on a “new” approach borrowed from Japan in building its standard machine tools, using design teams called “Wolfpack.”

Diversification is planned to help level out some of the cyclicality inherent in the machine tool industry but without going too far afield. The purchase of Valenite from GTE illustrates this philosophy. By adding cutting tools to its industrial products division, Milacron rounded out its line of other products, such as cutting fluids, grinding systems, and coordinate measurement machines. The other thrust in Milacron’s diversification, the plastics division, is currently the company’s most profitable enterprise, contributing 46 percent to earnings with only one-third of overall sales. This division, which manufactures injection molding machines, reaction injection machines, extruders, blow-molders, and extrudable blow-molders, is also notable in that it uses an FMS for the manufacture of many products, thus allowing Milacron’s manufacturing systems group to advertise that Milacron “practices what it preaches” regarding the utility of FMS.

The Wolfpack strategy is planned to reinvigorate Milacron’s manufacture of “standard” machine tools, beginning with the Maxim line of horizontal machining centers. The Maxim line does not represent any large advance in product technology, but rather embodies significant improvements in quality, functionality, and affordability. The Wolfpack team met its cost goal of a 40 percent price reduction over previous models; it reduced the number of parts from previous Milacron machines by over two-thirds; and it designed the system so that it could be produced in half the time. The design was also more responsive to customer needs. For example, during the design phase, Wolfpack engineers visited a number of customers to see Milacron machines and others in operation on the shop floor. Surprisingly, this was the first time that many of these engineers had ever seen these machines in actual use. Many of the lessons that they took away from these experiences were incorporated into the Maxim designs. For example, Milacron engineers discovered that the company’s previous line of horizontal machining centers had a tendency to spray oil, making the machine distinctly unpopular with users.

Maxim machines are proving to be a successful product line; however, the standard machines group of Milacron is still experiencing difficulties due to other machines such as grinders and vertical machining centers that represent older designs and manufacturing methods.

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7 In 1992, its R&D expenditures were 4.3 percent of sales, and it is taking part in a $4 million Cooperative Research and Development Agreement (CRADA) with Lawrence Livermore.
8 This strategy was first applied successfully within Milacron in the plastic machine division to ward off the threat of Japanese imports.
9 Milacron opened a new plant in South Carolina in 1990 to manufacture the Maxim line but was recently forced to close it and consolidate operations in Cincinnati because of overcapacity.
Mazak Corporation: Highly Automated Production

Mazak Corporation (Mazak) is a subsidiary of Yamazaki Mazak, a leading Japanese machine-tool builder. Its Florence, Kentucky, facility is the oldest Japanese machine-tool transplant in the United States (established in July 1974). Mazak focuses on the large market for CNC lathes and machining centers. Unlike most transplants, Mazak is more than just an assembly plant and machine-tool distributor. It lacks a full R&D capability, but is arguably the most sophisticated machine-tool manufacturing plant in the United States. It features an almost fully automated manufacturing capability. Mazak argues that this level of automation is necessary for quality and efficiency. Since the capital investments have already been sunk, it also gives Mazak increased flexibility during cyclic downturns in the market, making it easier to retain full employment during these times. The firm complements this capital intensity with a sophisticated workforce, hiring many community college graduates from the local cooperative education program for entry-level production positions.

Hurco Companies, Inc.: Global Partnerships

Since its reorganization, Hurco has become one of the more profitable machine-tool firms in the United States. It is a midsized company with just over 500 employees and 1991 sales of $80.8 million (Jablonski, 1992). It designs and produces controllers and EDMs and it assembles CNC machining centers. Hurco has plants in the United States and Great Britain, and has recently opened a new $7.5 million plant in Indianapolis. Nearly half of Hurco's sales are outside the United States, primarily to Europe, generating consistently higher profits than its domestic sales.

Hurco's competitive advantage stems from its partnerships with Taiwanese firms. Hurco imports Taiwanese "iron" and adds the controller to make a CNC machine tool. Hurco attempted to gain exemption from the VRAs to sell these composite machines unrestricted in the U.S. market. This request was ultimately denied, but not before Hurco was vilified somewhat by negative testimonies from competitors such as Bridgeport Machines.10

Fadal Engineering Company: A Growing Market Niche

Fadal is the largest manufacturer of low-cost ($40,000 to $100,000) vertical machining centers in the United States but is a much smaller company than either Ingersoll or Cincinnati Milacron; it had 200 employees and revenues of $81.5 million in 1991. It is a relatively recent entrant into the machine-tool industry, switching from a job shop catering to the Los Angeles aerospace market to a machine-tool manufacturer in 1982. Fadal's business began to take off in 1987 with the introduction of VRAs on machine centers and has expanded dramatically in the recent recovery. Since 1992,

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10Michael S. La Monica, Jr., Vice President, Marketing and Sales, Bridgeport Machines, Inc., Statement before the U.S. House of Representatives, Committee on Foreign Affairs, Subcommittee on International Economic Policy and Trade, July 22, 1992.
sales have more than doubled, to over $165 million/year, and employment has increased by 40 percent to 280 employees. Like Ingersoll, Fadal is a family-owned business and is naturally secretive regarding profits, productivity, and R&D investment; however, net profitability has been estimated as being quite high, reaching 12 percent in 1990 (Jablonowski, 1992). Fadal primarily serves the domestic market, with exports accounting for only 10 percent of sales.

The firm has made some product innovations in PC-based and parallel-processing controllers, but competes primarily on quality and cost. Fadal representatives were very open regarding quality control. Here, Fadal appears to be following a two-pronged strategy: Develop close ties with suppliers and distributors, and continually improve the product through incremental changes. Since the company views proper servicing as key to quality, it regularly forgoes sales rather than compromise quality. For example, Fadal will not sell its controllers or rotary tables as separate components, stating that it is difficult to control their implementation and use with other machines. Similarly, the firm is unusual among machine-tool makers in that it will not install others' controllers on its own machines.

Distributors are responsible for servicing what Fadal sells (outside of Fadal's home base in Southern California) and are therefore a critical component in Fadal's quality strategy. Fadal pays its distributors well—more than twice the norm—and expects loyalty and exceptional customer service in return. Understandably, the turnover in Fadal's distributor chain is very small; the company claims to have a large waiting list of those who would like to sell Fadal machines.

The incremental improvements in quality are mostly generated internally, but Fadal also ties itself closely to its suppliers to ensure consistent quality and timely response. Fadal is vertically integrated; it manufactures almost all components in house, even standard electronic gear, such as transformers. For those components that it does purchase, Fadal uses multiple sourcing, but this does not prevent it from building strong relationships with key firms. The company does not squeeze key suppliers on price unless it is clear that they are becoming noncompetitive. It also pays its bills promptly, putting Fadal first in line with its suppliers when rush orders are submitted. Finally, the company will often work with a supplier to develop certain critical parts, such as inverters, and will even allow the supplier to market these jointly designed items to other machine-tool manufacturers.

Internally, Fadal takes an almost paternalistic approach with its employees. Because it is nonunion, it pays its employees top dollar and even provides them with free safety shoes and one free meal a day. In exchange, the work week is 48 hours, and many employees will put in their own time on a regular basis. Fadal does not have a standard training program for its employees, but stresses cooperation and learning on the job. All managers and engineers are required to spend their first year rotating through the jobs in the factory. Fadal has only eight engineers, not all of whom hold

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11 These innovations were developed, in part, under contract by Gibbs Computing. Fadal makes good use of interchangeable parts and mostly eschews custom orders, preferring to sell from a catalogue. However, other firms follow these strategies, so it is difficult to attribute these factors to Fadal's claimed cost advantage.
degrees. Instead, the company relies upon individual initiative for most product advancements.

The capital stock at Fadal may be characterized as old; some of its machine tools are approaching 100 years of age. However, these machines are continually updated with new controllers (mostly from Fadal itself) and other hardware, such as rotary tables. What newer machines Fadal has tend to be its own.

**Haas Automation, Inc.: Manufacturing Efficiency**

Haas is one of Fadal's main competitors at the low end of the protected vertical-machining-center market. While Fadal's line will run up to $130,000, the most expensive Haas machine lists at $79,900, although the less expensive machines are the most popular. Haas is a very recent entrant into the machine-tool business, starting with a rotary table and then developing its own vertical machining center in 1988. It has grown dramatically over the last five years; with a target of selling 800 machine tools in 1993, it actually sold 832.

Haas sells almost exclusively to U.S. firms, usually avoiding the California market, which Fadal dominates. It builds standard machines on a schedule and sells them as a commodity. Although willing to stockpile unsold machines, Haas has not yet had to do so.

Haas representatives stress that the firm's competitive advantage stems from efficient manufacturing. It certainly is not interested in "high-tech" products, declining all offers for technology transfer from the national laboratories and stating that such technologies are useless to Haas.

Haas makes its capital investments based on cost-benefit analyses. For example, a recent analysis led the firm to purchase a new machining center rather than add a second shift for a particular manufacturing application. Haas is family-owned and has plowed its profits back into new equipment, buying the latest machines from all over the world, including automated machining cells that allow it to run a limited lights-out shift.

The firm encourages employee loyalty and productivity through a generous profit sharing plan, and workers average 20 to 40 hours of extra pay per month through this plan. Haas, however, offers little formal training to its staff. Skilled workers, such as machinists, are hired from outside the company, and most employees are simply trained on the job as required to operate one or two machines. It is still unclear how Haas and Fadal will adapt now that the trade barriers protecting their main product have been allowed to lapse.

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12The 14 machines that Haas sold in 1992 and the 44 sold in 1993 in the United Kingdom made that country the firm's largest export market.
TAKING THE LEAD IN FUTURE TECHNOLOGIES

Not all machines require the latest in technology. Being a year or two behind in innovation is hardly of great concern to manufacturers of hand-operated drill presses and lathes, and as we have seen in the previous section, firms pursue any number of competitive strategies other than reaching for technological superiority. However, higher-technology products tend to result in products with higher added value, and they also tend to require higher skills and more technological infrastructure. Thus, U.S. firms that concentrate on the high-technology end of the market have the opportunity to gain competitive advantage through the nation’s strength in technology innovation.

As shown in Table 5.1, the United States is among the world leaders in the R&D of many manufacturing technologies, including areas pertaining to machine tools (see Appendix F for a detailed discussion of key machine-tool technologies). However, in a number of important areas, such as CNC machines and FMS, the United States has been overshadowed by the Japanese, the Germans, and to a lesser extent, the Italians (not shown in the table) in introducing these technologies into the marketplace. As discussed earlier, the United States led in the initial development of those technologies; the failure of U.S. firms to create competitive CNC products contributed greatly to the decline of the industry in the early 1980s. As in other industrial sectors, the United States leads in the laboratory but trails on the shop floor.

Table 5.1

<table>
<thead>
<tr>
<th>Key Technology</th>
<th>Age (years)</th>
<th>Research Leaders</th>
<th>Market Leaders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layered manufacturing</td>
<td>5</td>
<td>US</td>
<td>US</td>
</tr>
<tr>
<td>Net shape manufacturing</td>
<td>5</td>
<td>US</td>
<td>US</td>
</tr>
<tr>
<td>Flexible fixture</td>
<td>5</td>
<td>US/G/J</td>
<td>G/J/US</td>
</tr>
<tr>
<td>Micromachines</td>
<td>5</td>
<td>US/J</td>
<td>US/J</td>
</tr>
<tr>
<td>Flexible machining systems</td>
<td>10</td>
<td>US/J</td>
<td>J</td>
</tr>
<tr>
<td>Flexible transfer lines</td>
<td>10</td>
<td>G/J</td>
<td>G/J</td>
</tr>
<tr>
<td>Artificial intelligence</td>
<td>10</td>
<td>US/J</td>
<td>J</td>
</tr>
<tr>
<td>New machine configurations</td>
<td>10</td>
<td>US</td>
<td>US/J</td>
</tr>
<tr>
<td>Precision machining</td>
<td>10</td>
<td>US/J</td>
<td>US/J</td>
</tr>
<tr>
<td>Waterjet machining</td>
<td>10</td>
<td>US</td>
<td>US</td>
</tr>
<tr>
<td>Improved formability</td>
<td>10</td>
<td>US</td>
<td>US</td>
</tr>
<tr>
<td>Cutting fluids</td>
<td>10</td>
<td>J</td>
<td>J</td>
</tr>
<tr>
<td>Cutting tools</td>
<td>10</td>
<td>US/J</td>
<td>J</td>
</tr>
<tr>
<td>Electronic data exchange</td>
<td>10</td>
<td>US/J/G</td>
<td>US/J/G</td>
</tr>
<tr>
<td>Display technology</td>
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<td>US/J</td>
<td>J</td>
</tr>
<tr>
<td>High-speed machining</td>
<td>15</td>
<td>US/J</td>
<td>US/J</td>
</tr>
<tr>
<td>Coordinate measuring machines</td>
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<td>G/US</td>
<td>G/US</td>
</tr>
<tr>
<td>Computer integrated manufacturing</td>
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<td>G/US</td>
<td>G/US</td>
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<td>Electric discharge machining</td>
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<td>US/J</td>
<td>J</td>
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<td>Laser welding</td>
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<td>Laser cutting</td>
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<td>Automated transfer</td>
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<tr>
<td>CNC</td>
<td>30</td>
<td>US/J</td>
<td>J</td>
</tr>
</tbody>
</table>

NOTE: G = Germany; J = Japan; U.S. = United States
In Table 5.1, it is interesting to note that the United States is more competitive in the newer technologies, such as layered manufacturing and micromasking. Where research began in the last 10 years, the United States leads in R&D in 13 of 15 key new technology areas, as determined by the literature and interviews with academic and industrial researchers, and it leads in the market in eight of these areas in terms of sales and product sophistication. Rapid prototyping, for example, is an area where 300 machines are now in use, and all but one of the manufacturers is American. In the older technologies, those ranging from 15 to 30 years in age, the United States leads in three of eight R&D areas, while it is the market leader in only one.

Although the United States is currently performing well in terms of R&D, there is no room for complacency. The United States has relinquished market control in some of the most important areas, including controllers, computer integrated manufacturing, artificial intelligence for advanced controllers, cutting lasers, flexible transfer lines, flexible manufacturing systems, and electric discharge machines. There are also other critical areas in which the United States is on the verge of falling behind its foreign competition: high-speed machining, precision machining, coordinate measurement machines, electronic data interchange, and micromachines.

The assessment of technologies in Appendix F identifies a number of obstacles associated with the technology transfer process. For example, there was an emphasis on product innovation rather than process improvements in the development of cutting lasers and electric discharge machines. The lack of proper standard-setting inhibits development of controllers and electronic data interchange systems. Users sometimes appear too short-sighted, as in the cases of electric discharge machines and artificial intelligence for controllers. Finally, poor communication between machine-tool makers and researchers has caused the United States to trail in the market development of fuzzy logic controllers.

OBSERVATIONS ON THE CHANGING COMPETITIVE CONTEXT

Though troubled, the U.S. machine-tool industry faces real opportunities to improve its global standing. Given the recent upturn in the U.S. market, the economic crises in Japan and Germany, the success of some U.S. machine-tool firms in adapting to new market conditions, and the nation's lead in key future technologies, U.S. machine-tool manufacturers could substantially improve their competitive position. Yet the industry still faces many obstacles, including tough competitors around the world, many with stagnating or declining domestic markets that may cause them to concentrate on increasing their own exports. And the industry still has difficulty in translating R&D leadership into market leadership.

In the next chapter, we examine options that federal, state, and local governments may consider to improve the machine-tool business environment within the United States and to assist U.S. machine-tool firms in becoming world-class competitors.

Governments in all the countries we studied—the United States, Japan, Germany, and Italy—participate in shaping their respective machine-tool industries and markets. This participation takes place through various laws, regulations, and policies, some of which are targeted on the machine-tool sectors, while most are more broadly applicable to industry as a whole. In most cases, government action is intended to help firms, although some government policies, such as export controls, can have a strong negative impact. In this chapter, we examine what the United States and other governments have done and the options that have been suggested for future action by government to help the machine-tool industry and broader U.S. manufacturing competitiveness.

The U.S. government has three broad policy interests in the machine-tool industry. First, machine tools are a key input to the manufacturing process. Thus, the government may want to ensure that U.S.-based firms have the capability to design and build state-of-the-art machines, so that U.S. manufacturers have access to the most up-to-date manufacturing technology. A second concern is that the United States maintain a sufficient domestic machine-tool manufacturing capability to meet national security requirements. Finally, the government has a general interest in the well-being of U.S. manufacturers because of their contributions to economic performance. While our study focuses on the machine-tool industry, many of its problems parallel those faced by manufacturers generally. Thus, some policies examined here might enhance the business environment for other small- and medium-sized manufacturers.

To the extent that governments choose to pursue actions on behalf of the machine-tool industry, this analysis suggests two guiding principles. First, government actions should be well coordinated across the range of policy instruments that affect the industry. Chapter Four discusses the determinants of competitive advantage for machine-tool firms. Because success in the machine-tool industry depends on success in each of these areas, action on one factor is intimately affected by actions on other factors. For instance, improved technology transfer will be to less effect if there is not simultaneous improvement in the supply of skills and capital. Second, policy intended to assist the machine-tool industry should not have detrimental effects on the rest of the economy. While this is always a concern in sector-specific policy studies, it is especially important here because machine tools are an important input into manufacturing in general. In assisting the machine-tool industry, the
government does not want to drive up the costs of new tooling or impede the access to new manufacturing technology for U.S. manufacturers.

We have divided our policy analysis into seven general areas, one for each of the structural factors discussed in Chapter Four. To recap, these factors are

- industry structure and related industries
- technology development and transfer
- workforce skills
- capital investment
- product liability
- demand stimulus
- international trade.

Although it is important that the government act in a coordinated fashion, it does not have the capacity to affect these seven structural factors equally. The machine-tool experts who took part in our focus groups (see Appendix G) were asked to rank various policies along two sets of criteria: importance to the industry and potential of the government to affect positive change. As shown in Figure 6.1, the industry representatives considered capital availability in general (and investment tax credits in particular) to be an important area in which government could have a large effect. Conversely, they considered technology an area of less importance, one in which the government could have relatively less impact.\(^1\) Several of the key structural impedi-
ments facing the machine-tool industry, particularly weak domestic demand and industry structure, are largely beyond direct government control. A key theme throughout this chapter is that some policy levers, primarily in training and technology transfer, can indirectly address these issues by encouraging networking among machine-tool builders and among builders and users. In most cases, the government actions examined here are aimed at small- and medium-sized manufacturers in general, not just machine-tool firms.

GOVERNMENT ACTIONS THAT MIGHT AFFECT INDUSTRY STRUCTURE

In one area, standard-setting, government might play a positive role in fostering cooperation. The benefits Germany and Japan have derived from standard-setting are described in Chapter 4 (although similar practices would be illegal under U.S. antitrust law). A number of technology developments—in particular, open control systems and integrated architectures—suggest a growing need for U.S. standards. The European Open Controller Initiative has succeeded in bringing the major European players together in an attempt to set new controller standards for the European market by 1995. Japan is undertaking a similar initiative. Joint government-industry consortia in the United States might contribute to the capacity (and willingness) of firms to create mechanisms that will result in the creation of standards for controls and other key elements of machine tools. Thus far, however, efforts have not proven successful (see the section on the National Center for Manufacturing Sciences [NCMS]). For standard-setting to succeed, the major stakeholders—makers of both controllers and machine tools—must be given greater incentives to cooperate.

GOVERNMENT ACTIONS THAT MIGHT AFFECT TECHNOLOGY DEVELOPMENT AND TRANSFER

U.S. machine-tool firms face difficulties incorporating the most advanced technology in their products because of the small scale of R&D investments, relatively poor links between manufacturers and users, and relatively poor links to universities and government laboratories. Many small U.S. machine-tool firms also lag international competitors in adopting best-practice technology in the design of production processes. In recent years, the federal and many state governments have begun to experiment with programs to improve the access of U.S. industry, and particularly SMEs, to product and process technology. Among these experiments are the shifting of research funding from defense to precommercial technology, establishing technology transfer programs in government laboratories, increasing direct funding of precompetitive research in industrial laboratories, and establishing manufacturing extension centers. None of these activities has been under way long enough to evaluate outcomes, either in general or for their potential benefit to the machine-tool industry specifically. Below is a description of how these activities relate to the underlying problems affecting the machine-tool industry.
Redirecting Federal Research

Federally funded manufacturing R&D will continue to be an important source of new knowledge for advances in the machine-tool industry. As discussed in Chapter Four, however, the utility of this R&D for the U.S. machine-tool industry is constrained by its focus on defense; a lack of industry input into the selection of projects; the emphasis on sophisticated products, rather than the manufacturing process; and by ineffective efforts to transfer technology. In recent years, the federal government has begun to address these issues. In fiscal year (FY) 1994, the U.S. government plans to spend $1.4 billion on manufacturing R&D focusing on three areas: intelligent manufacturing equipment and systems; integrated tools for products, process, and enterprise design; and advanced manufacturing technology infrastructure.\(^2\)\(^3\) Funding has increased for programs directed at precommercial technologies, such as the Department of Commerce's Automated Manufacturing Research Facility. The Department of Defense has also increased funding for dual-use technologies.

The federal government has also acted to improve firms' access to technology within federal labs. Although the National Institute of Standards and Technology (NIST) and NASA have had cooperative agreements with industry for years, legislation in the late 1980s greatly increased this level of activity and included other important government research institutions, most notably the Department of Energy's national laboratories. Government laboratories now have authority to sign CRADAs with any outside organization, including businesses, universities, and consortia, and to spend laboratory funds to participate in collaborative research endeavors. The federal laboratories have also made efforts, through such organizations as the Federal Lab Consortia for Technology Transfer, to match firms with appropriate resources within the laboratory system. For instance, the Department of Energy and NIST have recently developed the National Machine Tool Partnership, which offers consulting services for machine-tool makers and users by national laboratory personnel, available regionally but accessible via a single national office (Department of Energy, 1993).

These programs have generated significant interest among U.S. manufacturers (U.S. Congress, 1993). Yet, questions remain about their value to the machine-tool industry. First, few of these programs provide direct benefits to most small machine-tool firms, which generally lack the technical sophistication and personal contacts necessary to gain access to government research efforts. Second, even for larger firms, negotiating CRADAs is still subject to delays, and concerns about intellectual property rights have not been fully resolved. Finally, many firms retain doubts about the commercial relevance of research in the national labs. Most of the focus group par-

\(^2\) Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) initiatives in the FY94 federal budget, April 8, 1993.

\(^3\) Civilian Industrial Technologies is one of nine subcommittees under the new National Science and Technology Council (NSTC) that was set up to coordinate the activities among federal agencies. The Department of Commerce, Department of Defense, Department of Energy, Department of Interior, Environmental Protection Agency, National Aeronautics and Space Administration, National Science Foundation, and Department of Agriculture submitted baseline data for FY93 R&D spending on manufacturing research to the NSTC. The NSTC structure replaced the old FCCSET committees.
Participants expressed strong reservations, although several participants who had
tworked with the laboratories viewed them favorably. Cincinnati Milacron has a
CRADA with Lawrence Livermore to study high-precision machining techniques.
Livermore and Milacron have both formally contributed $4 million to the project, but
Milacron’s in-kind contribution largely consists of funds it has already devoted to
related activities. Milacron is cautiously optimistic that the project will help them
develop new products.

In the short term, it may be desirable to make the CRADA negotiation process faster
and to resolve the remaining intellectual-property issues. In the longer term, policy-
cmakers will address the question of whether the massive funds devoted to research
in government institutions might not be spent more effectively in other ways.

Direct Support of Industrial Research

In the past, the government funded R&D in industrial laboratories (other than basic
research) only if it was directly applicable to a government mission, such as defense.
The main exception to this mission-oriented pattern was the allotment for indepen-
dent R&D (IR&D) that has usually accompanied defense R&D funding for large sup-
pliers. Recently, however, the federal government has begun funding some precom-
petitive, proprietary research in industrial laboratories via two mechanisms: core
funding for industry consortia, such as NCMS, and grant programs such as NIST’s
Advanced Technology Program (ATP) and the Department of Defense’s Technology
Reinvestment Program (TRP). Such programs not only aim to supplement R&D
funding within firms, but also to increase the links among firms by providing finan-
cial support for collaborative research projects.

NCMS is a cooperative research consortium among roughly 180 U.S. manufacturing
companies (including some machine-tool firms) established under the National
Cooperative Research Act of 1984 and organized in late 1987. The consortium is
jointly funded by the DoD, the Air Force, and industry participants, in an effort to en-
sure more employer input into the research agenda. The federal government con-
tributes up to 60 percent of research costs for NCMS projects, which are conducted
in university, industry, and federal laboratories.

The NCMS is involved in a wide spectrum of activities, although the consortium has
faced various difficulties. The participation of small- and medium-sized firms has
been limited. Its first major project, the Next Generation Controller (NGC), suffered
from a lack of industry leadership and has not yet had a significant commercial im-
 pact (see Appendix D).4 Guided by a panel of industry experts, NCMS aimed to
develop and validate an open system architecture that would help CNC controllers
become a commodity product, build on U.S. strengths in computers and data
communication, and help U.S. industry recapture the controller market from
FANUC. Industry experts generally regard the technical work as good. However,

4This project originated in the Air Force, which had little success in getting industry to adopt the stan-
dards.
only a few CNC firms have joined the NGC effort, because U.S. CNC firms currently compete on the basis of proprietary architectures, so that an open architecture is fundamentally against their existing strategy. In areas where firms have greater common interest, however, NCMS, like other consortia, such as SEMATECH, may provide a useful mechanism for government participation in large-scale industry projects.

ATP, authorized by the Omnibus Trade and Competitiveness Act of 1988, seeks to accelerate the development of new product and process technology by awarding cooperative research and development agreements between government and individual firms for precommercial research. Funds are awarded through a competitive process focused on both technical potential and business promise. Winners may use the government funds entirely within their own firm or may use them to collaborate with other firms or with government or university laboratories. The firm sets its own research agenda but must contribute at least half the cost of the project to ensure the government of commitment. Firms retain rights to any intellectual property generated by an ATP project and are exempt from Freedom of Information Act disclosure.

These characteristics appear to make ATP a promising program. The competitive award process based on industry proposals focuses government funds on the technologies that industry regards as important; the cost-sharing provisions help decrease the chances that government funds will go to wasteful projects. The program’s sponsorship of collaborative projects among firms and with research institutions should help build cooperative networks. For instance, several large machine-tool firms are currently involved in ATP-funded joint ventures with auto companies and other potential customers. The three machine-tool firms that have won individual ATP awards (Saginaw Machine Systems, Ingersoll, and Giddings and Lewis) view the program favorably. Ingersoll, which generally shuns participation in government programs (see Appendix E), has an ATP project. In an interview, Saginaw Machine Systems personnel said that the ATP paperwork was minimal and that their ATP award allowed them to pursue a collaborative effort with researchers at the University of Michigan that would not have been possible otherwise.

ATP is only three years old, and little evidence is available to assess its performance. Pennsylvania’s long-standing Ben Franklin Technology Partnership is similar to ATP in many ways and may shed some light on its possibilities. Ben Franklin funds pre-competitive research in firms via a competitive award program, although unlike ATP it is organized around four independent regional centers, each associated with local universities. While there are no sound quantitative data on the overall impacts of the program (for instance, Ben Franklin collects information on jobs gained by its grant recipients but not on jobs lost), there is an extensive list of companies that have commercialized products with help from the program’s awards. Ben Franklin’s clientele consists of small, entrepreneurial firms interested in high technology. While several machine-tool firms are Ben Franklin clients, they are far surpassed by those in the computers, electronics, and biotechnology industries. Ben Franklin differs from ATP, however, in that the former focuses on small firms while the latter is open to firms of all sizes.
ATP will probably benefit the machine-tool firms willing and able to make use of it. Of the $187 million that has been distributed in ATP awards, $35 million has gone toward manufacturing technologies and recipients, with $3.4 million going to individual awards to three machine-tool firms. However, the ATP program will likely have difficulty reaching the smaller firms that are so central to the health of the machine-tool industry. Many firms may be unable to compete effectively for ATP awards because of their low R&D budgets, which will limit their ability to cost-share, and their lack of experience in finding partners for joint ventures, or may be unable to finance commercialization even after the ATP-supported research is complete. For instance, Saginaw is currently deciding whether to commit the funds necessary to commercialize a product developed with ATP-supported research. As ATP becomes more popular and the applications increase, machine-tool firms may also have difficulty competing for awards with firms in other industries with more vibrant markets than those faced by even the most innovative machine-tool firm.

Manufacturing Technology Extension

Manufacturing Technology Centers (MTCs) are regional centers focused on the needs of small- and medium-sized firms. Unlike ATP, consortia, and CRADAs, which aim to transfer new technology to leading-edge firms, the MTCs aim to help the average SME adopt best-practice technology: new quality-control techniques, shop-floor reorganization, or more advanced production equipment, for instance. In addition, MTCs can provide firms with seminars on technical and business topics, employee training programs, assistance gaining financial services, and help applying for federal programs. NIST already supports seven MTCs. Current plans call for a network of 20 to 30 MTCs and 120 to 140 smaller Manufacturing Outreach Centers (NIST, 1992). The centers are jointly funded by federal, state, and local funds, as well as by fees from firms participating in Center programs.

Centers are awarded to regional groups on a competitive basis and are designed to specialize in services deemed most useful to local firms. For instance, the Great Lakes MTC in Cleveland focuses on training in an on-site facility at a local community college. The California MTC has programs in defense conversion, organizes training programs through the community college system, and helps arrange contacts with the many university and government laboratories in California. The Midwest MTC in Ann Arbor involves small firms in collaborative research projects that they could not afford individually.

In addition, several states have run manufacturing extension programs over the last decade (Chapman, Clark, and Dobson, 1990). These programs provide valuable insights into how the MTC program might affect the machine-tool industry. The Cleveland Advanced Manufacturing Program (CAMP), part of Ohio's Edison project, is one of the most well-respected examples of a state-run technology extension center (Mt. Auburn Associates, 1992). CAMP's central activity is providing consulting and information services to the 10,000 small- and medium-sized manufacturing firms in the greater Cleveland area. It also runs research and training programs and manages the Federal Great Lakes MTC. In 1992, CAMP's budget was about $11 mil-
lion, with the large majority of funds coming from state, federal, and other grants, and roughly $1 million came from membership dues and fees paid by participating firms (CAMP, 1992).

The MTC program is likely to be useful to the machine-tool industry in several respects. First, these centers can help machine-tool firms adopt new product and process technologies in their operations. The experience to date with state programs is that firms that decide to use extension center services generally regard the services as very useful. In a survey of firms that had used CAMP, 75 percent reported the program had saved them money, 65 percent that it had increased productivity, and 60 percent that it helped them retain key customers (CAMP, 1992). Nonetheless, extension centers have reached only a small number of firms. CAMP has so far provided substantial help to only 4 percent of local firms, while 17 percent have attended seminars or received less intensive CAMP assistance; it is not clear whether resources or lack of demand has limited the scope of activities. Firms queried about extension centers in our focus groups and interviews ranked such services as the least useful of the government policy options we mentioned (see Appendix G). However, respondents displayed a great divergence in their interests, with some very enthusiastic and others quite skeptical that extension programs had anything to offer them. Often, there were many competing assistance programs available in a locality, confusing potential users. In addition to greater coordination, policymakers may also wish to encourage MTCs to provide a broader range of services. Very few, for example, seem to have active efforts to promote exports or to help machine-tool firms develop better access to local financial services.

In perhaps one of their most important roles, the MTCs may also act as a catalyst to help machine-tool makers and users establish networks for sharing technology development, training, marketing, or other activities (Shapira, 1990). Regional firm networks have already proven successful in northern Italy, Denmark, and Germany, and in the last few years have begun to develop across the United States (Rosenfeld, 1992; Firm Connections, March/April 1994). One of the oldest and most extensive firm networks in the United States is among electronics firms in the Silicon Valley, where the multiple linkages among universities, large companies, and multiple SMEs have enabled the region to respond effectively to the rapidly changing global computer market. Among emerging U.S. networks, metalworking is one of the most common sectoral focuses (Sommers, 1992). Although machine-tool makers themselves have so far not played a major role in these groups, many are located near metalworking networks.

The MTCs can organize events to bring firms together to share information, can build trust, and can act as independent brokers for joint activities. For instance, the MidAmerica MTC sponsors a regional apprenticeship program and has helped metalworking firms in Wichita create a supplier network of 20 small firms (The Kansas Manufacturers Association), which bid together on jobs too big for any individual firm (RAND focus group). In 1992 a survey was conducted of ten U.S. manufacturing networks of metalworking firms; eight of the ten formed with help from a regional extension center or similar state- or regional-level program (Lichtenstein, 1992).
Another way in which MTCs may help the machine-tool industry is by increasing the sophistication of small- and medium-sized machine-tool users, thus potentially increasing domestic demand. However, MTCs would have to expand their operations greatly to have an impact in this area. Furthermore, many firms that have been helped by MTCs do not seem to become major purchasers of machine tools. MTCs have limited staff and have difficulty maintaining expertise in a large number of specific technology and business areas. Thus, they often choose to focus their efforts on more general consulting services applicable to the large number of local firms needing basic assistance rather than offering more specific services to a select number of more advanced firms. The firms they help do not often have a great need for sophisticated machine tools. In the Cleveland area, for instance, if CAMP clients need a machine tool, they can often buy a used one at 10 cents on the dollar or can upgrade conventional equipment by adding a printed-circuit board control.

**Regional Applied Technology Center**

Finally, the German Fraunhofer Institutes represent a type of technology transfer organization that might have potential application in the United States. As described in Chapter Four, the Fraunhofer are regional centers specializing in particular technology areas. These centers combine government-funded basic research (like that of NIST laboratories) with proprietary research under contract to particular firms. While their regional focus is similar to the MTCs, their contract research service is unlike other U.S. programs. In addition, the Fraunhofer personnel policies promise the frequent reassignment of researchers between industry and public-sector laboratories. The AMP program in CAMP consciously follows the Fraunhofer model but on a very small scale. Recently, the Fraunhofer Institute has expressed an interest in establishing a facility in the United States, apparently with the encouragement of the Big 3 automakers and other large U.S. firms. Their experience in European operations leads these firms to believe that a U.S. Fraunhofer would provide important support to their suppliers. The government could consider supporting the creation of a Fraunhofer Institute in the United States or establishing a similar program under the auspices of the MTC program.

**GOVERNMENT ACTIONS THAT MIGHT AFFECT WORKFORCE SKILLS**

Although the United States fares poorly compared to its main rivals in providing education and training for the machine-tool industry, there are a number of recent local, state, and national initiatives that are directly addressing the skills problems of machine-tool makers and the wider metalworking community. This section will first review four main types of current programs: education and training providers, local training consortia, retraining, and national skill standards. It will then outline options for improving existing policies, as well as new mechanisms for breaking out of the vicious circle of low-skill supply and demand analyzed in Chapter Four.
INITIAL EDUCATION AND TRAINING

Apprenticeships

Historically, union-controlled apprenticeships for men in their late 20s supplied the bulk of skilled workers for the metalworking industry. As our analysis of the Current Population Survey reveals (see Figure 6.2), these apprenticeships have declined significantly in importance, with many large employers abandoning their programs entirely in the early 1980s. In their place, however, several states have initiated youth apprenticeship programs, with the aid of demonstration project funds from the Department of Labor (Hamilton, 1990).

Pennsylvania, Wisconsin, Oklahoma, and Massachusetts chose metalworking as one sector for their pilot programs. Pennsylvania modeled its efforts on the key principles of successful European apprenticeships. Each local site must begin by estab-

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Figure 6.2—Apprentices as a Percentage of Metalworking Employment, 1979–1991

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5RAND interviews and focus group; Rogers and Streeck, January 1991.
6The DoL's Office of Work-based Learning provided funding for ten demonstration projects in 1990, which were coordinated by Jobs for the Future.
7These principles are (a) using the work place as a learning center and integrating school with work; (b) giving employers, educators, and workers joint ownership of the system; (c) measuring outcomes in terms of common standards of proficiency; (d) emphasizing flexibility and "learning to learn"; (e) integrating secondary and postsecondary credentials; and (f) promoting the value and status of manufacturing employment.
lishing a firm commitment from local educators and employers to take part in all phases of development. The sites are constructing new curricula and forms of assessment that are designed to fit with the development of national skill standards for metalworking (discussed later in this section). Students enter the program in 11th grade and can continue through the associate-degree level at a local community college, accumulating a total of more than 5,000 hours of training. They initially spend two days per week in on-the-job training, where they earn an $80/week allowance, and three days per week learning in a classroom with a newly designed team-teaching environment that integrates academic and vocational subjects. In its first full year of operation (1992–1993), the state’s six demonstration projects enrolled 105 students and signed up 76 employers. The initial year was judged such a success that, although federal funding has run out, the governor provided resources to extend it statewide, with the addition of ten new training sites in 1993–1994.

The launch of the youth apprenticeship program, however, has not been without its problems. It has faced opposition from some labor unions, who fear that youth apprenticeships may undermine what remains of their traditional apprenticeship system and that young people will be exploited as cheap labor. The unions also argue that it is unfair to concentrate on training young people at a time when many older metalworkers are being laid off or not receiving training. The program has likewise faced some difficulties recruiting young people: “Schools would rather send their students to college than into manufacturing,” said Pennsylvania program coordinator Sharon Wherley; “[a]ll the incentives favor the college route.” The program has had to fight against parents’ and teachers’ misunderstandings of modern manufacturing and against the low status of vocational education and training programs. It has had less difficulty attracting employers, though some were forced to pull out because of the recession, and others, according to Wherley, have done it “partly out of altruism and sense of community spirit,” rather than because of an economic calculation of the benefits outweighing the costs.

**Community Colleges and Cooperative Education**

Many states and localities have taken a somewhat different approach to raising the skills of individuals entering metalworking, moving away from apprenticeships to a community- or technical college–based system. The distinction between the two models of initial training is often blurred, with community colleges typically playing a role in the instruction and certification of apprenticeship programs (as in

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8As students get older, the training becomes more work based, and the allowance increases.

9The numbers at each site will expand as new cohorts of students enter the program. There was roughly a 10-percent attrition rate in the first year, as some students were unable to meet the minimum academic standards.

10Pennsylvania has received a grant from a foundation to improve its relationship with the unions and is engaged in ongoing discussions with the AFL-CIO and its affiliates.

11Employers pay the trainee’s allowance, supply a mentor for each person, and often take their best people away from production to provide the instruction. The introduction of youth apprenticeships has also convinced many of the need to upskill the rest of their workforce, which generates additional costs, as well as benefits.
Pennsylvania, Michigan, Providence, Tulsa, and Baltimore), while college-based courses will often place students part-time with local firms. This is particularly true in well-established cooperative education programs, like Cincinnati’s, where students alternating between college and the workplace can acquire anything from an associate degree through a master’s in engineering. Analysis of the Current Population Survey indicates the greater reliance of metalworking firms on college-based education for technicians; Mazak’s plant just outside Cincinnati, for example, uses the associate degree as the main entry-level qualification for its production workforce.

Community college programs have some distinct advantages over traditional apprenticeships: Individuals are clearly defined as students, spending only a limited amount of time in actual production work; the courses fit well with the American emphasis on the college route and, at least in theory, offer the potential for individuals to continue to degree-level programs; and they may better deliver the broad academic grounding that individuals require to cope with rapidly changing technologies and occupational categories. But there are also some major drawbacks to many college-based programs. They will often have to make do with technologically obsolete equipment that is either donated or sold at a discount by manufacturers or the DoD. When they do invest in more state-of-the-art machines, this equipment is often poorly utilized. One of the problems many colleges face in attracting able students is the difficulty of placing them in permanent jobs with employers; local firms often will not hire individuals without prior work experience, and even if they do make new hires, they will then fire them during the next recession (Grubb et al., 1992). The historically cyclical nature of machine-tool employment compounds a more general difficulty colleges face: During recessions, demand for their courses increases even as state and local governments cut their budgets (Betts and McFarland, 1992).

**Local Consortia**

Another approach that cuts across the boundary between initial and further training is the formation of local training consortia involving metalworking firms and education providers. Wisconsin, for example, had a long history of apprenticeships in the metalworking sector, but this ended in the 1980s when the large companies abandoned their apprenticeship programs. In an attempt to fill this skill gap, the state has set up the Regional Training Partnership, which has an ambitious set of objectives: to develop competency-based skill standards, revive traditional apprenticeships, explore other entry-level training routes, improve dislocated-worker training services, and more. Some of the distinctive features of the Wisconsin approach are

- giving workers (usually through organized labor) equal representation with employers in the design and operation of the consortium

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12The rate of transfer into four-year degree programs has in fact been declining (Grubb, 1991).

13This section is based on interviews with Joel Rogers and Eric Parker, two organizers of the Wisconsin training program, and supporting written materials.
• a network of workplace education centers that focus on improving basic skills for the existing workforce

• the construction of a common modular framework for metalworking training that can accommodate initial and further training.

The requirements for employers who join the consortium are very stringent: They must devote at least 3 percent of payroll to training to recognized skill standards and must revise job ladders so that promotion is on the basis of skill rather than seniority. The consortium stresses the potential benefits to employers: a chance to screen potential hires with no obligation to retain them, the opportunity for small firms to offer recruits broader training than an SME could on its own, and, most importantly, a mechanism for moving toward a higher-quality, higher-skill production strategy. Large firms attempt to diffuse best training practices by making high-quality training a requirement for their suppliers.

Several other organizations, such as the Oregon Advanced Technology Consortium (Skinner, 1990) and CAMP, mentioned earlier, are using skill development as a central component of a local network to upgrade manufacturing.

Teaching Factories

A more concrete version of the local network concept is the teaching factory. The National Center for Manufacturing Sciences has set up three such factories (in Toledo, Ohio; St. Louis, Missouri; and Huntington, West Virginia), with plans to eventually establish a network of at least 150 Manufacturing Application and Education Centers (MAEC) (NCMS, July 1993, p. 4). These teaching factories are designed to provide small manufacturers and local higher education institutions with information, training, and a testing-ground for the latest technologies. An ambitious example of a teaching factory not affiliated with the MAEC network is the Center for Advanced Technologies established by Focus:Hope in Detroit.

Focus:Hope is a community organization in the heart of Detroit that was founded by Father William Cunningham after the 1967 riots. This organization is now concentrating its efforts on a three-tiered education program that begins with Fast Track, goes on to the Machinist Training Institute (MTI) and culminates with the newly established Center for Advanced Technologies (CAT).

• **Fast Track.** Fast Track takes students from all Detroit-area high schools, shooting for the top 20 percent of graduates. To get into the program, students must have at least 8th-grade level math and reading; this eliminates roughly 50 percent of applicants. Fast Track uses state funding to give them an intensive seven-week, computer-based course that is said to raise math levels by an average of 2.5 grades and reading by 0.7 grade. There is as much emphasis in the program on building the right attitudes and motivation as on basic reading and math. The program is run by a former drill sergeant, and students must turn up each day at 8 a.m.; two absences or late arrivals result in dismissal. Those who complete the program are placed in either jobs or a further education program—or they can
enter MTI (roughly 90 percent successful outcomes). Focus:Hope will only accept performance-based contracts for its students.

- **MTI.** The MTI consists of two 1,000-hour modules that provide students with basic machining skills on the different types of machines, along with continuing education—accumulating one year's credits toward an associate degree—in math, communication, theoretical material underlying metalworking, and rudimentary CNC skills. MTI was set up in the former headquarters of Ex-Cell-O, a leading machine-tool manufacturer, which left Detroit in 1981. One of the reasons for its departure was the difficulty of replacing its aging white, male skilled workforce. Focus:Hope is attempting to fill this skill need, at the same time placing minorities and women in jobs that have historically been closed to them. MTI has had more than 900 successful trainees since 1981, with placements in 125 different firms, more than half of which had never hired a woman or minority. One criticism of MTI is that it allows firms to "cherry pick" workers before they complete the full training course.

Trainees at MTI earn $6 to 8 per hour when not in instruction and most qualify for a $50 per week allowance during training to help them survive. Thirty-five percent of those who complete the first module go on to module 2, which includes CNC programming, pre-engineering math, heavy CAD instruction, and 4 hours a day working in the CAT on contracts for a separate for-profit subsidiary it has established, TEC Machining. The tuition per trainee is $7,750, which is paid for by a combination of state and federal programs. Roughly half of all trainees complete the course, with most who leave being placed successfully in jobs. Poverty is the biggest single cause of dropouts: The family income of completers averages $10,000, while that of dropouts averages $4,500. Despite this poverty level, students are asked to pay $10 a week from their own pockets for the training to make them demanding consumers of the instruction they are receiving. MTI and Fast Track plan to grow by 50 to 100 percent a year.

- **The CAT.** The most ambitious part of Focus:Hope is the new CAT, which was conceived in 1986 and is scheduled to take its first official entry class this year. CAT has already raised more than $62 million from the Departments of Defense and Commerce to set up a state-of-the-art manufacturing facility, complete with climate-controlled rooms for precision cutting and tooling, its own power-generation system, and a multimedia learning center that will both be the basis for most of the self-paced instruction and a resource for the wider manufacturing community. The total cost of outfitting CAT is estimated at $100 million. It will be equipped with solely U.S.-built equipment.

The graduate requirements for MTI are the entrance requirements for CAT, along with a minimum six months of work experience, which could be acquired within Focus:Hope. CAT has set up a consortium with six leading college engineering departments to develop its totally modular course and grant degrees. The course is designed to last up to six years, with multiple exit points leading to associate, bachelors, or masters degrees. Each student has a 60-hour-a-week commitment, with 48 hours on the shop floor and 12 hours of off-job instruction, including the
latest CAD technology and German and Japanese language skills. Toward the end of the course, students may assume management positions within the CAT and learn all of the financial, inventory, and other sides of the business. The course modules will be developed with a grant from the National Science Foundation (NSF). CAT's objective is to develop engineers with a more applied training than traditional university programs, both among its own graduates and those of the consortium members. In the process, it has broadened Focus:Hope's vision from the local community to improving U.S. manufacturing competitiveness.

Through TEC Machining, the CAT will be a fully operating factory. The TEC now has multimillion dollar production contracts with Detroit Diesel and Ford. It views these products as the "report card" for its students. TEC claims not to be competing directly with local auto suppliers, since it has built-in inefficiencies—as soon as a worker becomes proficient on one tool, he or she is moved to a new job. These jobs are performed by a mix of trainees and permanent staff, who all wear two hats: trainer and worker. All profits from TEC are plowed back into the CAT, which hopes to eventually be self-financing (not counting start-up costs). The Detroit Diesel contract provides a good test of CAT's flexibility, since TEC must juggle 160 different parts, with lot sizes that vary from month to month, while maintaining a just-in-time production system. The eventual capacity of the CAT is intended to be 450 trainees, with the hope that universities and local employers will also place people in the facility, both as faculty and trainees. Focus:Hope has also provided retraining for some union members.

CAT is relying heavily on the latest instructional technologies, designing a multimedia package for simple lathe instruction that it will market nationally. All the machines on the shop floor will be linked in a fiber-optic network along with PCs and CAD equipment. The goal is to remain technologically ahead of the best firms in the area, as a way of elevating the skills and sophistication of U.S. manufacturing, "creating a curve of obsolescence" among current machine-tool users. CAT tries to keep a real-world focus, however, by pairing students with outside mentors who will take them on site visits and provide advice. CAT is not trying to do basic research but rather to be on the cutting edge of implementation for the latest technologies.

Several elements may limit the transferability of the Focus:Hope model. The first is per-trainee cost, which, particularly for the CAT, is very high. To make wider use of this unique facility, CAT has signed agreements with Wayne County Community College and its consortia of area universities to open the CAT program to their students and to disseminate its electronic library and other multimedia instructional materials to a wider industrial and academic audience.

A second limitation is the dependence of Focus:Hope, like many successful community organizations, on its charismatic leader, Fr. Cunningham. He has combined a powerful set of messages—creating equal opportunities, restoring manufacturing competitiveness, rebuilding the inner city, ensuring national security—to gain the required support. Several people familiar with the organization commented that,
short of cloning Fr. Cunningham, it is unclear whether Focus:Hope can be translated into other settings.

Retraining: The California Employment Training Panel (ETP)

A promising model for raising the skills of adult workers is the California Employment Training Panel (ETP). This initiative was set up a decade ago to provide training to unemployed workers and to those in danger of being made redundant (Applied Management and Planning Group, 1992, p. 7). It is funded by setting aside 0.1 percent of corporate unemployment insurance premiums, with each company paying a maximum annual payment of $7 per employee. This mechanism raised $81.2 million in 1992, which was used to fund projects through a competitive bidding process. Many small metalworking firms have received ETP grants to provide courses in English as a second language, statistical process control, and total quality management. The state chapters of the National Tooling and Machining Association (NTMA) use ETP as a means of providing the unemployed with basic machining skills and an exposure to CNC and CAD. Given the recent spate of layoffs in California aerospace firms, there are up to ten times as many applicants as places in the four-month course. The ability to screen applicants carefully is important to the NTMA, since it only receives payment for individuals who are placed in a job that they then hold for at least 90 days. Focusing on retraining may be particularly important for the machine-tool industry, as the Department of Labor projects that the demand for machine-tool operators will decline by 28 percent in the next decade.\(^\text{14}\)

National Skill Standards

The federal government has recently played a major role in creating national skill standards. The Department of Labor has provided funding to the Council of Great Lakes Governors (CGLG) and the NTMA to develop a set of voluntary skill standards for metalworking occupations. This initiative is still in its development phase. As a first step, the CGLG and NTMA conducted a benchmarking exercise to compare U.S. skill training with that in Germany and, to a lesser extent, with that in Denmark and Japan. CGLG and NTMA have not attempted naively to copy foreign systems, but rather have searched for general principles of governance and processes that could then be modified to fit the U.S. context. For example, they recognize that a U.S. skill standard will need to be modular, so that it can accommodate both initial and further training courses, many of which will be part time. They have also recognized that a voluntary national scheme will need to have flexible criteria to embrace the different state approaches. With this in mind, they have adopted a model called ISO 9000 for setting international quality assurance guidelines. This specifies certain broad processes that programs must meet to qualify for the national standard—i.e., a structured plan with the strong support of industry and education, certified instructors, continuous assessment, and high-stakes testing at the end of the training. They

\(^{14}\)These projections are based on an extrapolation from the sharp fall in machine-tool employment that occurred in the last decade.
have also recognized the limitations that the U.S. legal environment places on any standard-setting effort: "People talk about world-class standards," said Professor Robert Sheets, a lead consultant on the project. "But in the U.S. you'd get sued if you adopted them, because some people might be excluded from participating" (RAND interviews, 1993).

Thus far, the process of developing national standards has been slow and criticized by some participants for failing to keep pace with developments at the local level (RAND interviews, 1993).

To actually get the skill standards used in the workplace, CGLG and NTMA want to use their network of governors to make the standards a requirement in any publicly funded training program. In addition, they are proposing a $10 million development fund, which would offer firms matching grants to cover the direct instructional costs (but not worker salaries) of any training they provide that conforms to the standards.

Options for Raising Skill Levels

There are a number of ways in which the federal government, building on the significant reforms of the last few years, might help U.S. machine-tool makers and users break out of the vicious circle of low-skill supply and demand. When considering the policy options outlined below, however, it is important to recognize the major limitations on the federal government's role in education and training:

- Excluding higher education, it provides less than 8 percent of total public education spending.

- There is a perception among employers that past federal training initiatives have been focused on remediating social disadvantage with a heavy accompanying regulatory burden, rather than being responsive to companies' needs and focusing on higher-level skills (RAND interviews and focus groups, 1993; Osterman, 1988).

- In the past, there has often been a lack of coordination among government departments involved in this area, which include the Departments of Labor, Education, Commerce, and Defense.\(^1\)

As a consequence, any initiatives that hope to raise skill levels will need to be developed in close cooperation with state and local machine-tool policymakers and employers, with the federal government playing pump-priming, coordinating, and leadership roles.

**Raise Basic Skills.** The poor level of basic skills of the individuals who are entering manufacturing from the U.S. education system was consistently identified by machine-tool makers and users as their most pressing skill problem (RAND interviews, focus groups). While the solutions to this general education problem are

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\(^1\)In the recent passage of the School-to-Work Opportunities Act, there was an unprecedented level of cooperation between the Departments of Education and Labor.
clearly beyond the scope of this study, there are some more specific measures that could potentially raise the skill levels of machine-tool recruits:

- Encourage greater links (e.g., school visits, work experience) between schools and local manufacturers. One purpose of such links would be to improve attitudes toward manufacturing by capitalizing on the introduction of computer-aided design and manufacturing (CAD/CAM) and CNC to show students how new technologies have transformed the work environment.

- Provide incentives for states to extend cooperative education programs and apprenticeships into the final two years of high school. These programs should have strict, minimum entrance requirements, so that employers are guaranteed that individuals will not require remedial training. Students who cannot meet the initial requirements should be given the opportunity to improve their basic skills through intensive learning, such as the computer-based Fast Track program (see previous section on Focus:Hope).\(^\text{16}\)

- Once the newly developed skill standards for metalworking are ready, disseminate them to individuals and teachers in schools and colleges to make explicit what jobs require. These skill standards will not be effective incentives for learning, however, unless those who attain them are rewarded by employers and unless jobs are organized to use the skills.

**Shift Funding from Equipment to Local Networks.** At present, much of the federal expenditure devoted to metalworking training goes to the purchase of capital equipment and facilities. Constructing a single, state-of-the-art site, such as Focus:Hope's CAT, can cost the government up to $100 million. While there are advantages to this teaching-factory approach (such as the abilities to simulate a real production environment, to promote the use of advanced technologies, and to develop centers of excellence for R&D on machine-tool-related training), there are also significant drawbacks: the limited population that any one facility can serve, which results in high costs per trainee; the difficulties of remaining "state-of-the-art" as the technology continues to evolve rapidly; and the often low utilization rate of such facilities.

An alternative approach would be to redirect resources to the development and support of local networks of metalworking firms, machine-tool distributors, and education and training providers (see below).\(^\text{17}\) Trainees could split their time between a shared, central training facility and member firms. The shared facility would provide instruction on the general-education components that underpin metalworking, as well as on the basics of machining, CNC, and CAD on a few general-purpose machines. Participating firms would provide on-the-job training on the latest tech-

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\(^{16}\) The 1994 School-to-Work Opportunities Act provides some of these incentives, but the funding is very limited.

\(^{17}\) The more sophisticated machine-tool distributors already have high-quality training departments that they provide as a service to their customers and a large supply of new machines on display that could be used for training.
nologies, perhaps under the guidance of a trainer from outside the company if no qualified person is available internally. The advantages of this approach could be

- improved relationships among local firms that could foster greater outsourcing and specialization
- better utilization of a firm’s equipment that is often used for only one shift
- an assurance that the training is relevant to employers’ needs and provides “greater bang for the buck.”

**Greater Sharing of New Instructional Tools and Best Practice.** A great deal of innovation is under way at state levels to develop new training courses, materials, and skill standards for the metalworking industry. Although some mechanisms exist for sharing information—such as periodic conferences organized by Jobs for the Future and the Department of Labor—more could be done to disseminate best practice and new learning materials. This is particularly important in the case of innovative training practices, such as the interactive video package for teaching individuals how to operate machines that Focus:Hope and other institutions are developing. As with basic research for machine tools, the government has provided the resources for this project, but not the mechanisms for its effective diffusion among training institutions and machine-tool users. In the future, the government could stipulate that any materials developed with federal support should be deposited in a clearinghouse, where they would be available for free to all interested parties. A logical “clearinghouse” for machine-tool materials might be the partnership between the CGLG and NTMA, which is taking the lead in the development of skill standards.

**Overcoming the Poaching Problem.** While the poaching of skilled machinists and other highly trained workers has become less of a problem of late due to the large downsizing of machine-tool users, it is likely to resurface as an issue whenever there is a more substantial recovery in manufacturing. The local firm consortia outlined above provide one potential mechanism for overcoming the free-rider problem that deters companies from investing in transferable skills. This could be achieved by making it a condition of membership in the consortia that firms provide a certain level of in-house training, thus ensuring a basic pool of skilled labor in the area. Consortia members could set up contracts with individuals that require them to work for the member firms for a certain number of years or else pay back part of the cost of their general skill training if they leave the local labor market, similar to a bank funding an employee’s MBA. Another means of reducing the poaching problem is to distribute the costs of training so that public funds are used to cover the provision of general skills, while companies provide more firm-specific skills. Due to the difficulties of separating these types of training in practice, this type of policy could take the form of matching grants to firms, based on the number of their trainees completing certified modules within the national skill standards.

A third alternative for overcoming the free-rider problem would be to introduce a requirement that companies spend a certain portion of their payroll on training. This would be similar to policies in place in Australia, Singapore, and France and to proposals made by the Clinton campaign (Clinton and Gore, 1992). Such a training re-
requirement, however, would be very difficult to monitor and enforce until a national skill standards and delivery system was firmly in place. There is also a danger that such a policy would discourage firms from recruiting new workers and encourage them to treat training as an accounting device necessary to satisfy the government, rather than an integral part of their overall strategy.  

**Incentives for Upgrading Skills.** Given the declining overall employment in the metalworking sector, it may make sense for the government to devote a greater percentage of its training resources to adults who have lost or are in danger of losing their jobs but who already have occupation-specific skills. This study has identified several types of policies that achieve this objective. One is the California ETP program, which places a small surcharge on firms’ unemployment insurance premiums and uses these funds to provide grants, on a competitive basis, to companies and/or other institutions that offer retraining programs. Similar programs already exist in 17 states and could be extended to the rest of the United States. Another would be a countercyclical training program similar to that of the Japanese Ministry of Labor, which identifies industries hard hit by the recession and provides them with a subsidy to retrain their employees. This initiative avoids the individual stigma attached to unemployment and gives firms an incentive to invest in the skills of their workers at all points in the economic cycle, since they know they can retain them during a downturn. The disadvantages are that it could be costly and open to abuse, because it is difficult for the government to assess the danger of layoffs, and that it could discourage restructuring that is sometimes necessary. A third possibility would be for both federal and state governments to provide funds targeted at retraining during recessions to community colleges, as now occurs in Canada. Currently, these education and training providers tend to face budget cuts because of declining state and local revenues during slumps—just when the demand for their services is increasing.

**Linking Training with Other Services.** Training works best when it is closely related to other services (such as technology extension, export marketing, advice on business process redesign, joint R&D) that help companies make the transition to a higher-skill strategy (Finegold, 1993). When training is offered on its own—even if it is free, like the AMT’s training scholarships—companies may not take up the opportunity, either because they do not perceive the need for the skills or because they do not have the capacity to deliver and utilize them. The Clinton administration has recognized the need to link these services in its proposals to expand Manufacturing Extension Centers and to create a new set of Regional Technology Alliances. These new institutions should, wherever possible, build on existing networks and seek to include education and training providers as key participants. The focus of such consortia should be to tackle simultaneously the issues of skill supply and how the workplace can be reorganized to better use the new skills.

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18The French payroll levy, for example, has been criticized for encouraging firms to waste money on expensive management-development courses.
GOVERNMENT ACTIONS THAT AFFECT CAPITAL INVESTMENT

Government can affect the flow of capital to small- and medium-sized businesses, such as those that make up the bulk of the machine-tool industry, through a variety of policies. The challenge is to redress failures in the markets that supply capital to smaller businesses without unintentionally creating larger problems through the nonmarket allocation of funds. The following are the four types of government policy most directly related to the machine-tool industry:

- government-supported lending (direct or guaranteed) to or investment in small- and medium-sized businesses
- banking and financial regulations that affect private flows of funds to such businesses
- special lending facilities
- policies that indirectly encourage lending by changing the profitability of such firms, such as ITCs.

Before considering each area in detail, it is important to note that there are clear limitations to what government can usefully do in this area. To the extent that the fundamental capital access difficulties result from the small size of these firms, effective governmental responses are limited. Some of the policies discussed earlier that attempt to create virtual economies of scope by interfirm cooperation have limited effectiveness here: The financial prospects of a firm remain firm specific. Smaller businesses need financial institutions with industry expertise, willingness to take risks, and flexibility in terms and repayment schedules. Direct government involvement is unlikely to do better than private lenders in these areas. If funds are made available directly or through guarantees based on liberal terms, there is a risk of creating the same incentives that led to the savings-and-loan crisis in a small-business lending program. Finally, government cannot easily improve the profitability and hence the creditworthiness of firms in a troubled industry. If other policies (or good fortune) improve the performance of the industry, investment in this industry should increase.

Government-Supported Lending to Small- and Medium-Sized Businesses

The federal government has existing programs that provide funds to small businesses. The Small Business Administration (SBA) is one source of capital for borrowers that would have difficulty obtaining funds elsewhere. SBA programs have more complex qualification requirements than bank lending, and businesses often must wait longer before receiving funds. While these restrictions can be eased somewhat, they prevent such programs from becoming a drain on the Treasury. The federal government cannot provide a large share of the funds flowing to small- and medium-sized businesses; neither would many argue that it should. State and local governments face the same problems in this area. To the extent possible, small- and medium-sized businesses should be "mainstreamed" into private-sector financial institutions. Export finance is one area where the federal government has long
played a role (through Export-Import Bank Programs), which is discussed separately below.

**Banking and Financial Regulations**

Financial regulation in the United States is not meant to handicap small- and medium-sized businesses, but it has seemed to have such an effect in recent years. Concerns about concentration of economic power in the United States have traditionally led to clear lines of demarcation between financial and manufacturing firms. Such concerns will probably continue to underlie laws and regulations that prohibit closer ties, like those seen in Germany and Japan. More recently, requirements for more extensive documentation and collateralization of bank loans have priced many small- and medium-sized businesses out of the market. The savings-and-loan crisis led to many of these new regulations that curtailed not only risky lending practices but also lending that, while comparatively safe, could not easily be documented as safe. Some of the overregulation has eased, with the White House at times lobbying regulators to be more sensible, but continued easing of bank controls could improve the access to capital of small- and medium-sized businesses without undue risks of financial instability or further drains on the Treasury from deposit insurance fund losses.

**Specialized Lending Facilities**

Perhaps more important than relaxation of financial regulation is the emergence of specialized lending facilities for small- and medium-sized businesses. As mentioned in Chapter Four, specialized lenders have arisen to finance the purchase of machine tools. Some of these lenders are financial firms that understand the industry, others are cooperatives, and still others are development programs attached to state and local governments. The role of the federal government in such facilities is to encourage them where appropriate, perhaps by linking banks into the consortia mentioned earlier, and to stay out of the way as much as possible. State and federal technology-extension centers could be a useful vehicle for government efforts to encourage the participation of such private-sector institutions.

**The Investment Tax Credit**

Investment tax credits can both increase the capital available to the industry and increase the demand for machine tools (by reducing their effective price). By wide margins, both producers and users of machine tools supported the restoration of the Investment Tax Credit (ITC) as the most effective government policy for aiding the machine-tool industry.\(^{19}\) (Of course, it is not surprising that both producers and users of machine tools would favor a reduction of their taxes.) Because machine-tool

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\(^{19}\)An ITC was part of President Clinton's original economic package submitted to Congress this past spring. This proposal would have a permanent ITC for small firms and a temporary ITC for larger firms. The ITC was dropped from the package before it left the Ways and Means Committee in the House of Representatives.
makers both produce capital goods and intensively use capital goods in their manufacturing processes, an ITC would have a dual benefit for them.20

The rationale for an ITC should be based on some concept of equity or efficiency rather than an (understandable) desire for lower taxes. Such a rationale exists: The income from long-lived capital assets is taxed more heavily than income from short-lived capital assets, and this divergence is most severe for smaller businesses.21 An ITC is one means of bringing the effective rate of taxation for short- and long-lived capital assets and large and small firms closer together. This rationale, however, supports not only the ITC, but also a number of alternative policies that produce similar results with different side effects.

ITC policies have varied widely over the last three decades. The ease with which these policies can be altered is one disadvantage of ITCs. As shown in Chapter Four, many past administrations and Congresses have attempted to use ITCs as a countercyclical policy with, at best, mixed results. Such instability in the tax code increases business risks and may depress investment. Alternatives, such as allowing capital assets to be expensed or further accelerating depreciation schedules (a weaker version of expensing), have effects similar to those of the ITC and are generally more stable features of the tax code. In any case, the ITC or alternative changes in the tax code would reduce tax revenues in the short run, and would produce effects well beyond the machine-tool industry and its customers.22 Using the plight of the machine-tool industry as a reason to significantly change the tax code is surely letting the tail wag the dog. If Congress and the administration choose to reduce the inequities and inefficiencies in the tax code, these actions will help the machine-tool sector as a beneficial side effect.

GOVERNMENT ACTIONS THAT AFFECT THE REGULATORY ENVIRONMENT

As discussed in Chapter Four, this study does not address the general regulatory environment affecting SMEs in the United States. However, it is worth mentioning one policy area of particular concern to the machine-tool industry: liability law.

Liability reform is a complex debate with vigorous advocates on all sides of the issue. It was beyond the scope of this study to assess the balance between protecting worker safety and reducing the regulatory burden on U.S. machine-tool firms. However, there is one area in which some reform seems warranted. Currently, machine-tool firms can be held liable for injuries caused by machines of any age, even if the machine’s safety features have been modified. The significant number of

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20An ITC will help buyers of foreign machine tools as much as buyers of domestic machine tools. A policy to restrict the ITC to U.S.-produced capital goods would likely run afoul of the General Agreement on Tariffs and Trade (GATT) and other trade agreements, and it not supported by U.S. firms (see Appendix G).

21Because capital assets are “written off” over time, the discounted value of the write-offs will be less than the purchase price of the asset. A firm is effectively taxed on this difference. Because capital access is a perennial problem for small firms, the effective discount rate of these firms is higher than for larger firms. Consequently, the depreciation allowances are worth even less to a small firm than to a large one.

22The short-run loss in tax revenue is likely to exceed the size of the entire U.S. machine-tool industry.
old machine tools used in the United States and the ease with which their protective equipment can be removed by users suggest that U.S. firms have reason to fear such suits. Removing the builder's liability for machines past a certain age, particularly if they have undergone significant modifications, would relieve machine-tool makers of this burden and remove one of their largest complaints about the arbitrariness of the system. It might also encourage firms to replace these unsafe machines with new, more efficient equipment. The proposed uniform product liability law (S.687) calls for limiting a party's liability to within 25 years of delivering the product. Such a reform would remedy the perceived inequities in the current system while preserving the incentive for current manufacturers to make safe machines.

GOVERNMENT ACTIONS THAT MIGHT AFFECT DEMAND STIMULUS

One of the most powerful policy levers available to government for stimulating demand is the ITC, discussed above. In addition, changes in procurement policy may also stimulate demand.

Despite the defense drawdown, the DoD will still procure significant numbers of machine tools and will probably have the largest direct impact on machine-tool purchases of any government agency. The "Buy America" act ensures that the great majority of machines purchased will be from U.S. manufacturers. Even though government procurement is a small fraction of the total domestic market (about 5 percent), many defense needs require advanced technologies and can provide an important market "pull" for new machine-tool technologies. For instance, the largest demand for certain manufacturing technologies for composite materials is due to DoD contracts. Consistent with its defense mission, DoD often coordinates with other agencies to use its procurement to foster new manufacturing technologies (e.g., Advanced Research Projects Agency, ATP). However, the beneficial impacts of past DoD procurement programs have been limited by the complexity of DoD contracting procedures, which have made it difficult for firms (like machine-tool makers) that are not primarily defense contractors to obtain DoD orders. Thus, the beneficial effects of DoD procurement policy will be limited until there are significant reforms in the defense procurement process.

GOVERNMENT ACTIONS THAT AFFECT INTERNATIONAL TRADE

As we have discussed, the machine-tool industry's primary barrier to export success has been its own heavy focus on the domestic market. Although that focus has begun to change, and may change further in the future, there are policy options that could help substantially in boosting the U.S. industry's trade performance. Four areas are most central:

- VRAs
- Export controls
• Export promotion
• Market access to Japan.

VRAs

The policy most explicitly designed to aid the U.S. machine tool industry was the VRA. Under the VRAs, which expired at the end of 1993, Japan and Taiwan agreed to limit machine-tool imports to the United States. This section examines the impact of VRAs in the 1987–1993 period.

In 1986, President Reagan, citing national security concerns over U.S. dependence on foreign machine tools, announced his intention to seek VRAs on several categories of machine tools from Japan, Taiwan, Germany, and Switzerland. Although the Germans and the Swiss declined to negotiate, VRAs on seven categories of Japanese and Taiwanese machine tools (vertical and horizontal NC lathes, non-NC lathes, machining centers, milling machines, and NC and non-NC punch and shears) were successfully negotiated and implemented in 1987, to be effective through 1991. In late 1991, President Bush announced his decision to extend the VRAs on NC tools through the end of 1993, when they were allowed to lapse by the Clinton administration.

Many U.S. machine-tool users oppose VRAs, because quotas are the most inefficient form of trade barrier, increasing costs to users and limiting their access to the most advanced machine-tool technology. Conversely, a large foreign producer with plants in the United States told us that, while it took no stand on the VRAs, it thought the firm benefited from stronger domestic content enforcement, since its U.S. value-added number exceeded those of many U.S.-owned domestic manufacturers. In the RAND focus groups, many U.S. machine-tool makers—including those who directly benefit from quotas—were reluctant to support trade restrictions, because they worried about retaliation against U.S. access to foreign markets, and because they felt they could compete against “fair” foreign competition (see Appendix G).

VRAs seem to have been effective at limiting U.S. machine-tool imports. Figure 6.3 illustrates the effects of VRAs on aggregate Japanese and Taiwanese imports to the United States. After rising steadily during the 1980s, the Japanese share of real U.S. machine-tool consumption peaked at 29.2 percent in 1988, one year after implementation of the VRAs. Japanese import penetration has been declining since and stood at 22.8 percent in 1992. The Taiwanese market share shows a similar pattern on a smaller scale, peaking at 3.6 percent in 1988 and declining in subsequent years. The VRAs, therefore, are correlated with a stabilization of Japanese and Taiwanese U.S. market share.

These aggregate data mask some interesting and important trends. Figure 6.4 shows the value per unit for two types of Japanese machine tools imported into the United States (lines) and the number of units of each type imported into the United States (bars). The VRAs did what they were designed to do: reduce the number of Japanese
Figure 6.3—Import Share of U.S. Consumption

Figure 6.4—Imports of Japanese NC Lathes and Machining Centers into the United States
units imported into the United States. Simultaneously, Japanese machines in the United States were becoming more expensive. Part of this increase is due to the rise of the yen against the dollar. However, it is also due to the Japanese machines moving upscale. In other words, the Japanese pursued something of a “Lexus” strategy, exporting smaller numbers of more expensive machines. Ironically, the VRAs encouraged the Japanese to compete with U.S. machine-tool makers in higher-end, more specialized markets, where the United States had previously dominated. These two trends, decreasing number of increasingly expensive machines, produce the relatively flat post-1986 import penetration curve seen in Figure 6.4.

In addition to limiting the number of high-end Japanese imports, the VRAs limited the number of low-end imports from Taiwan. There is evidence to suggest that this barrier may have opened an important market niche for low-end machine tools in the United States. Several small U.S. machine-tool firms aggressively moved into this market just after the VRAs were put in place. Some of these firms had survived in small-niche markets with annual sales of less than $10 million before the VRAs and increased sales by a factor of ten once the quotas were put into place (see Figure 6.5). It is not clear how well this segment of the U.S. machine-tool industry will survive now that the VRAs against low-cost Taiwanese imports have been removed.

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23This trend is independent of the VRAs, since it is true for all Japanese production, including exported units not restricted by the VRAs.
The VRAs also encouraged the Japanese to set up machine-tool operations in the United States. As Figure 6.6 shows, the number of Japanese transplants increased dramatically after the VRAs were put into place. Some of the early Japanese plants in the United States, such as Mazak and Okuma, have had beneficial effects, providing high-quality jobs and demonstrating best-practice production technology and organization to U.S.-owned firms. The majority of facilities established after VRAs, however, were assembly plants or warehouses, since the Japanese already had sufficient or excess capacity in their home factories to serve the U.S. market. In addition, the VRAs encouraged the Taiwanese to move production for the U.S. market to Thailand to avoid the restrictions, while providing new market opportunities for other countries, such as Spain. The VRAs thus contributed to the expansion of worldwide machine-tool production capacity.

Export Controls

The export control policies of the United States were developed during the Cold War to prevent the Soviet Union and other potentially hostile nations from easily acquiring advanced Western technology with military applications. As discussed in Chapter Four, this system has been a serious impediment to machine-tool exports. Most significantly, the export control regime has erected barriers to U.S. machine-tool exports to all nations, not just those on the control list, by creating a time-consuming, bureaucratic export licensing process. The U.S. machine-tool industry can-

![Figure 6.6—Number of Japanese Machine-Tool Transplants in the United States](image-url)
not continue to face these impediments to export and hope to restore its position as a world leader in machine-tool production. The U.S. export control regime, therefore, should be reformed to reflect the current realities of international politics and global economic competition.

Perhaps the most critical element of export control reform is to reexamine the licensing procedures that precede export of machine tools (and any item on the U.S. commodity control list). The current process includes the Departments of Defense, Commerce, and State, and any number of other agencies that can claim some legitimate interest in trade or national security policy. Licensing often takes several months to complete, because these agencies must be satisfied that the customer overseas is not going to reexport the product to some U.S. adversary or use it to some disruptive purpose. Meanwhile, U.S. competitors, where licensing is handled by a single department, complete the process more quickly. While the U.S. process serves a purpose for many single-use military items, it could be streamlined and centralized for items that are used primarily in commercial applications, like machine tools. One simple way to hasten the procedure is to put a time limit on licensing. If the Department of Commerce does not provide a reason why the sale should be delayed within some period after the license application is filed—one month, for example—then the exporter would be free to proceed. This type of regulation would focus the export control regime on transactions that are clearly least desirable and would let routine exports occur.

A second element of reform would be to review the items on the U.S. Commodity Control List. Historically, export controls in the United States have focused on “dual-use” technology, items that have key military uses but also have significant commercial demand. Given the recent developments in international relations and the current state of international competition, there is some question as to whether such items belong on the commodity control list. The COCOM regulations, as interpreted by the United States, prevent export of basic CNC machine tools. Yet, basic CNC machining capability is widely available worldwide. Because many of the defense-related tasks requiring machine tools can be accomplished using standard CNC technology, the ability of the United States, or even all the Western allies acting together, to maintain effective control on machining technology is almost nonexistent. The ending of COCOM in March 1994 provides an opportunity to reexamine the types of machine tool subject to control.

Export restrictions on machine tools may still be merited in specific cases. For example, certain types of high-precision machine tools that are available from only a few firms worldwide may accelerate the development of nuclear weapons by nations that do not now have them. In these cases, the United States and its allies have clear incentives to control machine-tool technology and a reasonable chance of success. Nevertheless, it is likely that licensing requirements could be eliminated for whole classes of machines and for whole groups of nations without increasing the threat to U.S. national security.
Export Promotion

As discussed in Chapter Four, U.S. machine-tool firms lack the export orientation, international marketing expertise, and institutional support to export their products in significant quantities. While some large firms have been able to expand exports in the last decade, there is an urgent need for most machine-tool makers to expand their export capabilities. In a very real sense, the future of the U.S. industry depends on how U.S. firms respond to this challenge. Several policies are designed to promote machine-tool exports that federal, state and local government might enact to assist machine-tool firms at the margin.

Because small machine-tool builders often have trouble procuring reliable export finance, expanded government assistance in providing and insuring export loans might help machine-tool firms develop more global marketing strategies. One new program that might serve as a model for future efforts to expand export finance is the U.S. Export-Import Bank (EXIM) “bundling” program. EXIM guarantees a “bundle” of money to a commercial bank specifically for export loans before the bank reviews any specific export finance applications. With this guaranteed sum, the bank is then able to provide export loans to U.S. and foreign customers at rates well below those that are available for comparable loans in the financial markets. The bundling program is particularly attractive to small- and medium-sized businesses, because it provides medium-sized loans—up to $10 million—and it is potentially quite accessible through local commercial banks and financial institutions. Because “bundled” loans have been made available only for exports to Latin America, however, they provide financing opportunities for only a limited number of transactions. For this type of targeted export finance program to significantly influence export opportunities for small business, it may be necessary to expand the set of nations and transactions for which these loans are available.

A second way in which the government could help to improve export orientation among small- and medium-sized firms in the United States would be to sponsor international conferences and expositions designed to educate U.S. firms about export opportunities. This type of program, which could be loosely modeled on the Department of Commerce’s auto parts program,\textsuperscript{24} would be best implemented through a partnership with industry trade associations and federal, state, or local government. In machine tools, for example, government might provide matching funds to trade associations for conferences designed to promote machine-tool export. The use of federal government resources overseas (embassy commercial staff, trade delegations, etc.) to promote attendance by foreign machine-tool customers could provide a stimulus to small businesses to become more export-oriented. These conferences could also help expose many small businesses in the United States to the basic steps in the export process, filling a clear need for better information and increased sophistication in small business export strategies.

\textsuperscript{24}The Department of Commerce currently cosponsors an export promotion program for auto parts with Japan’s MITI. The program includes regular conferences in the United States and Japan in which representatives of the Japanese and American auto industries meet to share information on their respective product lines, business needs, and procurement practices.
Market Access to Japan

The Japanese market for machine tools, like many other product and service markets, features significant nontariff barriers to foreign competition. Clearly, increasing access to the Japanese market would help non-Japanese machine-tool producers, but foreign rather than U.S. producers may be the primary beneficiaries of a more open market. The United States has a relatively large share of Japan’s machine-tool imports—much larger than its share in other markets. In fact, the United States has traditionally exported more machine tools to Japan than to Germany, a market of similar size that is largely open. A more important problem for U.S. producers may be poor export performance overall, rather than the closed Japanese market.

Certainly, more open markets for machine tools in Japan should be a U.S. government policy goal, but this goal is one aspect of a larger goal: more open markets in Japan for all products. Nonetheless, we do not believe that machine tools are a high priority for market-opening discussions with Japan. There are other product areas in which the United States could expect larger sales to an open Japanese market than machine tools and in which the quality of American goods so far exceeds that of the Japanese as to counter potential claims that Japanese purchase patterns reflect the quality of product and not a closed market. The latter point is important because, while import restrictions helped protect the infant Japanese machine-tool industry in the 1960s and early 1970s, no longer are the barriers the result of explicit tariffs or quotas. Sometimes the barriers include customs and inspection practices. More often, the problems result from discriminatory distribution networks, impenetrable industrial groupings (keiretsu) that have long-term user-supplier relationships, licensing requirements and regulations that are effectively discriminatory, and attitudes about foreigners and foreign products. Many of these facets are not directly under the control of the government.

The data and analysis of Japan’s trade record, as presented in Chapter Four, speak for themselves. As Japan has developed the world’s largest machine-tool market over the last decade, it continues to import a far smaller percentage of its machine-tool consumption than other industrialized nations. While the major reason for this is undoubtedly the fierce competition among large, highly productive machine-tool makers, economic analysis (Penubarti, 1993) indicates that Japan imports significantly fewer machines than would be expected in a free trade environment.

While something seems amiss, we cannot construct a defensible bill of particulars. It is also difficult to argue that access to the Japanese market is essential to restoring this industry to health. Access to Japan may be important in the future, but other problems deserve attention first. Therefore, special trade initiatives focused on the machine-tool industry distinct from overall discussions on manufactured goods do not seem warranted. If the United States adopts a managed trade strategy, machine tools should probably not be one of the four or five industries singled out for special

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25 The Japanese market is very much open de jure. There are almost no formal legal restrictions on machine-tool imports and no formal restrictions significant on imports of other manufacturing products.
treatment; the industry is comparatively small, and the United States has no clear advantage.

Finally, it is unclear that the best way to help the machine-tool industry is by addressing trade in machine tools directly. Given the importance of domestic markets in general for machine-tool makers, and given the lack of experience in exporting found in U.S. machine-tool firms, expanding the demand from U.S.-owned firms for machine tools may be the most successful strategy to aid the machine-tool industry. One way of doing so is to increase exports of U.S.-manufactured goods, particularly those of metal-using industries. Thus, paradoxically, a broadly based trade initiative with Japan (or elsewhere) may be more effective for the machine-tool industry than an initiative focused specifically on machine tools.

CONCLUSION

There are a variety of ways that government actions affect the U.S. machine-tool industry. This chapter has reviewed past and new initiatives in the seven areas that are crucial to competitive advantage in machine tools. The final chapter reviews the main reasons for decline of the U.S. machine-tool industry, and describes how policy options can be coordinated in a new strategy to address the problems of this sector.
Chapter Seven

SUMMARY AND POLICY OPTIONS

Entering the 1980s, the United States was the world’s largest producer of machine tools. By the end of the decade, the U.S. machine-tool industry was less than half the size of those of Japan and Germany and had resorted to protectionism to defend portions of its domestic market. Despite strong growth in 1993, the U.S. machine-tool industry is still far from recovering its lost market share. What explains the decline? And what strategic policy options are open to the government for approaching the problems of the machine-tool industry?

This chapter addresses those questions in four sections. First, the main reasons for the decline of the U.S. machine-tool industry are reviewed. Next, four broad government strategies for the machine-tool industry are outlined. There is then a more in-depth discussion of the set of policies that our analysis suggests provides the best chance of improving the competitive position of the U.S. machine-tool industry. Finally, to the extent that a study concentrating on a single industry allows, observations are made on how this strategy might benefit U.S. small- and medium-sized manufacturing enterprises more generally.

FACTORS UNDERLYING THE DEMISE OF THE U.S. MACHINE-TOOL INDUSTRY

Two sets of factors explain the decline of the U.S. machine-tool industry.\(^1\) The first set includes four historical conditions that were in place in the 1980–1982 period when the drop in U.S. machine-tool production occurred:

1. There was a sharp fall in domestic consumption on which U.S. machine-tool makers were heavily dependent.

2. U.S. machine-tool makers’ strategy for coping with highly cyclical demand was to accumulate order backlogs during boom times and work them off during recessions. This time, however, the backlog strategy backfired. When demand began

\(^1\)At the outset of this study, we attempted to use a broader definition of “machine tools,” which includes both the traditional machines that cut and form metal and the new technologies that improve this process (e.g., CNC, sensors) or handle new materials used in manufacturing (e.g., plastics and advanced ceramics). Our ability to use this expanded definition of the machine-tool industry, however, was limited by the ways in which the government and industry associations collect data on this sector (see Appendix H).
to pick up, the Japanese were ready with a greatly expanded, more efficient machine-tool production capacity that enabled them to fill new orders within weeks, rather than months.

3. The Japanese were able to offer more flexible, reliable tools than U.S. makers—at lower prices—because of a significant first-mover advantage in product technology (the first affordable microprocessor-based machine-tool control) and a large productivity advantage due to modular production and other process innovations.

4. The U.S. machine-tool industry’s price competitiveness with foreign firms was undermined by the high value of the dollar during this period.

While these factors are critical to explaining the decline of the industry in the early 1980s, they do not explain the failure of U.S. machine-tool makers to adapt to the new market conditions. Why were Japanese rather than American firms the first to turn U.S.-invented CNC technology into successful products for the mass market? As the dollar weakened in the latter half of the 1980s, why were U.S. machine-tool makers not better able to compensate for the shrinking domestic market by taking advantage of the huge surge in worldwide machine-tool demand?

The answer to these questions lies in a second, deeper set of factors that affect the competitiveness of machine-tool makers. The basis for success in machine tools has undergone dramatic technological and market changes since the introduction of CNC tools in the late 1970s. In the new environment, three broad elements contribute to competitive advantage: the structure of the industry and related sectors; the inputs (capital, labor, and technology) on which the industry relies; and the relationship between machine-tool makers and their users, both domestic and foreign. A fourth element, the relationship between government and industry, will have a major effect on all three factors.

**Industry Structure and Related Sectors**

Competing successfully in the new global machine-tool market requires major new investments in capital goods, training, export marketing, and other areas. Compared to its main competitors, the United States is at a disadvantage in making these new investments, because it lacks

- a sufficient quantity of large machine-tool makers that can build these capabilities in-house
- strong institutional mechanisms for cooperation among smaller firms.

The strength of supporting industries also helps explain the success of Japan relative to the United States in the last decade. Japanese machine-tool makers benefited, because FANUC emerged as the *de facto* world standard for machine-tool controllers with as much as 70 percent of the global market. By contrast, both the United States and Europe were hampered by having several competing firms, all with different
proprietary CNC standards and none with a major commitment to the machine-tool industry.

**Inputs and Supporting Infrastructure**

To keep pace with the increasingly rapid rate of change in machine-tool markets, machine-tool makers require a supporting infrastructure that can help them develop three key inputs: (1) new technologies, (2) high levels of skills, and (3) capital for new equipment and financing sales.

Technology is naturally a key factor in the success of a capital-intensive industry, such as machine tools. Despite its recognized lead in past, present, and many future areas of basic research related to machine tools, the United States has been less successful than its main rivals in developing commercially viable technologies, especially in the critical period from the late 1970s to mid-1980s. There are three main sources of major new product innovations in machine tools: external research institutes, machine-tool makers’ R&D departments, and customer and supplier firms. U.S. universities and federal labs conduct top-quality basic research but, until recently, have had little incentive to focus on projects with strong market potential or to devote time and resources to developing their work with industry. U.S. machine-tool makers, with very few exceptions, have not had sufficient in-house R&D capability to do this more applied research. Machine-tool makers in all countries cite customers as the primary external source of new product ideas. U.S. machine-tool makers, however, have suffered from arm’s-length relations with machine-tool users, as opposed to the close inter-firm relationships and joint product development that exist in Japan and to a lesser extent in Germany and Italy. One exception to this is defense, where close partnerships between makers and users have kept the United States a world leader in new product development of high-precision, specialized machines for this sector.

The industry’s second key input is labor. Small improvements in product or process design generated by workers within firms can lead to incremental innovation, which, in turn, leads to competitive advantage for machine-tool makers. But, because of relatively low skill levels, the makers and users of machine tools in the United States have been less prepared than their counterparts in other countries to contribute to continuous innovation and to make the best use of new technologies. This relative skill gap results from the poor basic education and occupational skills that individuals who enter metalworking typically receive from the U.S. school system; from the lack of engineers working in the sector; and from the factors, such as poaching, that deter U.S. firms from investing in training.

In addition to new technologies and high-level skills, a third input that appears to be lacking in the United States is adequate access to capital. Two types of capital are crucial to success in global machine-tool competition: (1) resources to invest in new CNC equipment that can boost productivity and flexibility and (2) capital to finance sales both at home and abroad. U.S. machine-tool makers lack access to both types of capital, resulting in low rates of investment in new technologies and difficulties closing deals because of a scarcity of capital for sales credits. The problem in the
United States is not overall capital availability, which was at historic highs during the period of the machine-tool industry's decline. Rather, the financial markets and banks in the United States, with the exception of a few specialized lenders, appear to be wary of providing funds to small, mature manufacturers for several reasons: high information and transaction costs, the low profitability of many firms, and the highly cyclical nature of their businesses. Publicly traded U.S. firms were not able to rely on the "patient capital" that helped their Japanese and German rivals expand in the early 1980s.

U.S. firms have been at a further investment disadvantage relative to their main competitors, because foreign governments have all provided sustained targeted incentives to manufacturers to invest in advanced industrial equipment—like CNC tools—spurring demand for the new machines among machine-tool users, as well as among makers. The U.S. government has periodically increased sales of machine tools through an ITC, but this temporary and often mistimed tax incentive has tended to shift demand from one year to another, rather than increasing capital investment in the long term.

Markets: Domestic Demand and Export Capacity

Like inputs and industry structure, the nature of demand in the United States for machine tools has hindered the industry's growth. U.S. machine-tool firms have concentrated on meeting the needs of their primary customers: the U.S. aerospace and automotive sectors. The problem for the U.S. machine-tool industry is that these sectors are shrinking, part of a longer-term decline in U.S. metal consumption. In addition, the kinds of machines U.S. customers have demanded have led machine-tool makers to concentrate on products that the rest of the world either does not want or in which the United States is not competitive. Large U.S. customers have demanded customized, rather than commodity, machines (the latter are cheaper and easier to export), and were slower than Japanese machine-tool users to make the move from dedicated to flexible CNC tools. Small U.S. job shops, on the other hand, have tended to be more sensitive to the price of machine tools than their counterparts in Japan and Germany, placing U.S. machine-tool makers in direct competition with lower-wage nations, such as Taiwan and Spain.

The ability to compete on a global scale is particularly important in machine tools, because it allows firms to serve specialized markets and still reach a sufficient customer base. It also helps them to weather the cyclical fluctuations in domestic demand. A weak capacity for exports has prevented U.S. machine-tool makers from compensating for poor domestic demand by increasing their share of foreign markets. Much of the problem lies with U.S. firms themselves, which concentrated on sales close to home rather than on developing a sustained presence in the world's most rapidly growing markets. The firms' ability to export, however, has also been hindered by a time-consuming export licensing regime and the lack of export supports available to many of their rivals.
FOUR BROAD GOVERNMENT STRATEGIES FOR THE U.S. MACHINE-TOOL INDUSTRY

The federal government could respond to the problems of the U.S. machine-tool industry in a number of ways. The set of options open to government policymakers can be organized using two of the major policy dimensions discussed in Chapter Six: (1) technology policy—ranging from a hands-off approach to a partnership between government and industry to create new competitive capacities—and (2) trade policy—ranging from protectionism to free trade. Trade policy could be thought of as a subset of technology policy, in the broad way in which the latter is currently used. We have separated them here because of the particular importance of VRAs for the machine-tool industry; the two dimensions are not antithetical, however, but rather should work in tandem as part of a broader approach to industrial competitiveness (Figure 7.1).\(^2\) Mapping the policy choices along these two dimensions yields four distinct strategies that the government could pursue: maintain past policies, leave the industry alone, protect and improve the industry, or help the United States become a global player. The pros and cons of each option are outlined below. Our analysis suggests the preferred long-term strategy is to help the United States become a global player, and the following section includes a set of measures for implementing this strategy.

Maintain Past Policies

One strategy open to the federal government would be to continue with the policies of 1987 through 1993. The government focused on supporting basic research, primarily for defense-related applications, while having little direct contact with

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<th>Technology policy</th>
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<td>Active</td>
<td>Protect and improve industry</td>
<td>Make the U.S. a global player</td>
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<tr>
<td>Passive</td>
<td>Maintain past policies</td>
<td>Leave industry alone</td>
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Figure 7.1—Strategic Options for the Federal Government

\(^2\)There is, of course, an almost limitless array of policies that the federal government could pursue. Figure 7.1 is intended as a way of conceptualizing the main strategic options open to the government with regard to building domestic infrastructure and trade policy.
machine-tool firms and on protecting the industry from Japanese and Taiwanese imports through the use of VRAs. This approach can be argued to have achieved its primary objective: preventing a further erosion of the U.S. machine-tool industry. It also entailed low administrative costs and roles that the U.S. government was accustomed to playing.

While the VRAs were relatively inexpensive for the federal government, they imposed high costs on large segments of the U.S. manufacturing community, which were denied access to some key types of tools at the best price available on world markets. Protectionism, by itself, also did not help U.S. machine-tool firms develop the new capabilities they require to compete effectively in global markets; indeed, if the continued use of protectionist measures meant that the quotas came to be perceived as no longer just temporary, then U.S. machine-tool makers would have even less incentive to expand outside the domestic market. In addition, the original rationale for imposing the VRAs—concern over maintaining an adequate defense production capability—has been weakened by the diffusion of CNC machines that can perform a wide array of functions. Our research has shown that, despite the overall decline of the American machine-tool industry, the United States remains very competitive in the production of the few remaining tool types tailored specifically to the defense industry. A final argument against the VRAs is that even most firms benefiting directly from protected markets do not favor the continuation of quotas (RAND interviews, focus groups).

The other main traditional thrust of federal government policy—investment in basic research—has helped give the United States a lead in many technologies related to machine tools. But much of this research has, until recently, had limited commercial applications, and in those few areas where a large potential market existed, the government has not focused on helping firms translate success in the lab into successful products. As a consequence, there has been little payoff for U.S. machine-tool makers from this major investment.

**Leave Industry Alone**

A second option open to the government would be to leave the fate of the U.S. machine-tool industry to the market, letting the VRAs lapse and providing little other federal assistance. After all, the United States, by definition, cannot have a competitive advantage in every sector, and this industry is not large in terms of either production or employment. Government involvement carries significant costs and may not help the industry solve its problems. Machine-tool firms, it could be argued, had six years of protectionism in which to restructure, and their recent results suggest that they no longer need government assistance.

The difficulty with this laissez-faire argument is that it reads too much into a cyclical expansion in U.S. demand, while ignoring the long-term infrastructure problems that have hurt the machine-tool industry. Governments in Japan, Germany, and to a lesser extent, Italy have worked closely with industry to develop the key inputs (capital, skilled labor, technology) and support the exports required to succeed in the new competitive context (see Appendices A through C). These governments believe
strongly that the strategic importance of a healthy machine-tool industry far exceeds the size of this sector. The benefit of a strong domestic machine-tool base most often cited is that it ensures domestic manufacturers access to the latest production technology; several sources confirmed that there is a one- to two-year time lag before the latest Japanese and German machine tools are available in the United States. This time lag becomes more significant as the product life cycle of machine tools continues to shorten. Since there are potential benefits in the design and implementation of new production systems that derive from close cooperation between machine-tool makers and users, a further decline in the U.S. machine-tool industry could hurt wider manufacturing competitiveness.

The results of our analysis suggest that the removal of VRAs without government efforts to improve the competitive position of U.S. machine-tool makers will, after the current investment boom ends, result in further reduction in the size of the U.S. machine-tool industry. Even with no government action, however, some U.S. machine-tool firms will continue to compete successfully in specialized markets (e.g., aerospace), in tools that demand customization and are thus difficult to fill through exports, and through joint ventures with overseas competitors.

Protect and Help Industry Improve

A third alternative for the government would be to put VRAs in place temporarily (perhaps in a modified form) while pursuing a more active strategy for improving the capabilities of the U.S. machine-tool industry. This policy would be similar to the strategy that Japan pursued in the 1960s, when its government protected an infant machine-tool industry until it was strong enough to compete internationally and then removed all tariffs and limits on foreign direct investment. One strong argument in favor of the VRAs in the short term is that the global recession has created a large overcapacity among Japanese and Taiwanese machine-tool makers. They will thus have added incentives to export to the United States, which has come out of the recession more rapidly than its main competitors.

If the VRAs are reinstated, they could be altered to avoid some of the negative consequences associated with the recent quotas. One option would be to focus the restrictions only on Japan, since it is unclear why the U.S. government would want to deny machine-tool users access to low-priced, low-technology Taiwanese imports. There is no evidence of unfair Taiwanese trade practices or a threat to national security, and U.S. machine-tool makers are unlikely to be able to compete in market segments where low labor costs are the key to competitive advantage. The VRAs on Japanese machine tools could then be kept in place until Japan reaches a specified target for increasing its machine-tool imports to a level approximating the other major machine-tool producing nations (which all import at least 25 percent of their tools versus less than 10 percent for Japan). It is not clear, however, how many U.S. machine-tool makers currently have competitive products that they are unable to sell in Japan because of nontariff barriers. In addition, there may be other sectors in which the United States has a stronger case for opening Japanese markets (e.g., auto parts) and that will indirectly benefit U.S. machine-tool makers by expanding their
customer base. A final option for the VRAs would be to alter the treatment of Japanese transplants to require a greater percentage of U.S.-based content to be exempt from the quota.

The rationale for sheltering some parts of the U.S. machine-tool market from global competition could be to provide sufficient time for the government and industry to implement a set of policies that would address the structural problems analyzed in Chapter Four. Many promising government initiatives relevant to small- and medium-sized manufacturing enterprises, such as machine-tool firms, have been initiated recently. It should be stressed, however, that the main onus for restructuring and building new capacities falls on the machine-tool firms themselves. A detailed set of policy options for helping machine-tool firms create new capabilities is presented in the next section.

Make the United States a Global Player

The final broad strategy that the government could adopt is to focus on helping the U.S. machine-tool industry compete more effectively in the international marketplace. The main distinction between this strategy and the previous one is in the approach to trade policy. The United States cannot expect to become a major global player if it relies on protecting its domestic market. Our analysis indicates that the global market for machine tools will probably become even more competitive in the near to middle term. U.S. machine-tool makers must become more active players in the international marketplace if they are to survive. As discussed in Chapter Four, there was a phenomenal growth in worldwide machine-tool demand from the mid 1980s until the recent recession. Almost all this growth occurred outside the United States, a trend we expect to continue, albeit in different countries (e.g., China) and in different product categories. Therefore, a continued concentration on the domestic market will not only cede growing foreign markets but will also deny the U.S. machine-tool industry the necessary economies of scale and scope needed to maintain its share of the domestic market.

POLICY OPTIONS: HELPING MACHINE-TOOL MAKERS COMPETE GLOBALLY

The following section outlines a three-part approach for helping the U.S. machine-tool industry become an effective global player:

- Improve the rate and effectiveness of technology adoption by fostering local cooperative networks that can provide a package of services beyond the capacity of most individual companies.

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3It should be stressed that a realistic objective for the United States is to become a major global player, not to regain its position as the world leader.
• Increase investment in the manufacturing infrastructure (e.g., basic research, transferable skills) and give greater emphasis in federal R&D to production processes and building closer ties between research institutions and firms.

• Shift the trade policy emphasis from protecting the domestic market to creating a more supportive climate for U.S. exports.

Underlying this policy approach is a view that the proper roles for the federal government are to concentrate on areas where the market alone will not provide sufficient investments; to delegate the delivery of those services to firms and local actors where possible; and to ensure that U.S. firms compete on equal terms in global markets. It does not suggest that the government should target the U.S. machine-tool industry for special assistance. The reasons for avoiding a targeted strategy are, first, that such policies have had limited success in the United States and abroad and may sometimes damage the economy as a whole; second, that if the government chooses to “pick winners” among sectors, the machine-tool industry does not appear to be a very good bet; and finally, that the problems of the machine-tool industry (such as the poor links between the makers and users of tools) are likely to be better addressed by an encompassing strategy focused on the metalworking sector, which accounts for one-quarter of all U.S. manufacturing, rather than on machine tools alone.

Build Industry Capacity Through Firm Networks

The investments and capacities required for success in the global machine-tool marketplace are beyond the scope of most individual machine-tool makers. One mechanism for obtaining greater economies of scale and scope would be to encourage mergers among existing firms. This policy has been tried and has failed in Britain, France, and to a lesser extent, in Japan. It does not appear necessary in the United States, where a long process of consolidation has already occurred, and the results of mergers have often been disappointing.

An alternative approach is to encourage firm networks. Networks are a stable set of relationships among independent companies—a way of organizing economic behavior that lies between market exchanges at one extreme and interfirm transactions on the other. The common interest linking firms is often both geographic and sectoral, as companies with related products and/or input needs create a cooperative venture. Networks can take a variety of forms: a cluster of small firms that form a partnership to produce a product, suppliers that are brought together by a large assembly plant, or some form of institution (e.g., industry association, chamber of commerce) that acts as a hub for local employers’ activities.

In the past, U.S. machine-tool firms thrived without networks because of a huge home market, few global competitors, and relatively stable technology. Today, a

4A leaked copy of a policy document prepared by the European Machine Tool Employers’ Federation reportedly recommends that the EC pursue a strategy of industry consolidation (Financial Times, July 7, 1993).
number of features of the machine tool industry make it well-suited to a network approach:

- The machine-tool industry is now characterized by rapid technological change, combining electronics and mechanics.
- It is composed predominantly of SMEs that are located in geographic clusters near the main end users of their products.
- Product development in machine tools works best when there are close links among suppliers, equipment makers, and end users that networks can foster.
- Networks can also increase firm specialization and the use of subcontracting in production, key factors in the success of Japanese and Italian machine-tool makers.
- The volatile nature of demand in specific machine-tool markets can lead to problems of overcapacity; networks provide a possible vehicle for responding more flexibly to these shifts in demand.
- The high degree of international competition in this sector reduces any antitrust concerns about oligopolistic behavior.

Our analysis has also identified barriers that will need to be overcome if machine-tool firms are to become more active in networks. Foremost among these is the historical reluctance of companies (both machine-tool makers and their large users) to cooperate (see Appendix G). Experience to date with networks in the United States and abroad suggests certain actions that can help build the trust necessary to gain firms’ involvement and make networks a long-term success:

- Start small with an activity (e.g., help in obtaining ISO 9000 certification) that is helpful and not threatening to local firms.
- Develop a clear mission for the organization so that it is not simply a “talking shop.”
- Hire a well-funded, independent broker that can bring participants together and mediate disputes.
- Build a sense of ownership among local firms for the network and its policies.
- Allow large firms, including foreign-owned companies, to participate, but not to dominate; this can be achieved by giving all members, regardless of their size, an equal vote.
- Emphasize “open programs,” such as technology demonstrations, training for general processes (statistical process control [SPC], reengineering), rather than concentrating on proprietary technologies.
- Conduct periodic, independent evaluations to determine whether the network is adding value and how the network can be improved.

Where such networks do not already exist, the federal government’s role should be to act as a catalyst by providing some basic support for a broker to coordinate activities
and information exchange. It should leave the main governance responsibilities to local actors. To help foster networks, the government should

- Extend the MTCs and support other initiatives (state programs, teaching factories) that help firms adopt best practices in the redesign of their production processes and can serve as focal points establishing new local cooperative networks.
- Transcend local boundaries by using the Internet and proposed National Information Infrastructure to increase the flow of information among firms and research institutions.

Even where U.S. networks already exist, they tend to be relatively small both in the number of firms involved and in the scope of their services. The government can encourage the expansion of these networks by providing them with matching funds to develop additional services that the firms could not afford in isolation. The government should create incentives for networks in the following areas:

- Education and training: Networks should
  - act as a coordination mechanism for increasing employer involvement in school-to-work programs
  - deliver courses for existing employees in general skill areas (CNC programming, CAD, SPC, etc.) through contracting with external providers or setting up cooperative training
  - share existing or new machines between colleges, where they tend to sit idle during the day, and local firms, where many machines are not used in the evenings and weekends.

- Access and use of capital: Networks should
  - reduce the information costs associated with lending to smaller manufacturers, which constitute the bulk of machine-tool firms, by including financial institutions and/or specialist machine-tool lenders in the local cooperative networks, as occurs in several Japanese prefectures
  - where banks are not directly involved, provide member firms with assistance in making credit applications or accessing government programs
  - finance joint purchases of capital equipment that member firms can lease to meet high demand periods.

- Export promotion: Networks should
  - include export marketing as one of the key services provided by new local cooperative networks; by focusing on the global rather than the purely domestic market, local firms have an increased incentive to cooperate, since, with a much larger pool of potential customers, they no longer need view their neighbors as their main competitors.
An additional potential benefit of networks is the role they can play in coordinating separate programs and services. Our analysis suggests that progress on one factor, such as technology transfer, without parallel improvements in skills and access to capital will not fully address the problems of the machine-tool industry. Networks are a natural vehicle for building synergies among services.

**Invest in the Manufacturing Infrastructure**

Networks, while a promising mechanism for increasing the collective capability and flexibility of the machine-tool industry, are still in their infancy in the United States. Even when fully developed, they will not provide all of the basic infrastructure investments—technology, skills, capital—that machine-tool makers require.

**Infrastructure for Technology Development and Transfer**

In general, U.S. machine-tool firms have not adopted the new CNC-based manufacturing technologies as rapidly as their competitors in Japan and Europe, and the large federal investment in science and technology research has not yielded the industry significant benefits. Since the 1980s, the U.S. government has tried two general approaches to rectifying these problems. The first effort, which began in 1986 with the Machine Tool Domestic Action Plan, was justified largely on national security grounds. Thus the Department of Defense led the government's manufacturing R&D efforts, through ManTech and DoD funding of NCMS. (The trade component focused on the VRAs.)

The second wave of policies began with the end of the Cold War, as the emphasis of government R&D activities started to shift from defense to more economic concerns. This new approach includes increased funding for commercially oriented manufacturing technology programs in the Department of Commerce and for dual-use programs at DoD.

Our research suggests the general emphasis of this new government approach is correctly placed. Nonetheless, the ability of the new programs to improve the generation and diffusion of new technologies among U.S. manufacturers, including machine-tool firms, will largely depend on the details of implementation and the distribution of funding among the various programs. Most of these programs had only just begun when this research was conducted, and thus, we were unable to offer a full assessment. However, our research does suggest a range of issues that these programs should address to improve the performance of such sectors as the machine-tool industry.

A successful technology policy for the machine-tool industry needs a balance between technology diffusion and technology development and transfer programs. Policies to enhance technology diffusion—the spread of best-practice product and process technology from the cutting edge firms throughout the industry—should be primarily addressed to SMEs, and the aforementioned regional networks are the best vehicle for reaching such firms.
Policies to enhance technology development and transfer aim to make the federal investment in R&D more relevant to industry and to speed the commercialization of new technologies. Although technology development and transfer programs should make strong efforts to attract SME participation, larger firms' internal resources and experience with government give them the best access to these programs. In many instances, new technology may reach small machine-tool firms through interactions with their much larger customers.

To help the U.S. machine-tool industry, a federal program of manufacturing R&D needs to increase the emphasis on manufacturing processes within the U.S. research establishment, as well as provide for commercialization as an integral part of the R&D program. The subject of this research ought to be manufacturing broadly defined, rather than just metal cutting or metal forming. As discussed in Chapter Five, the best opportunities for growth within the current machine-tool industry (encompassed in our broad definition of the industry) are to continue to expand beyond metal cutting and metal forming to manufacturing with other materials (plastics, composites) and the entire spectrum of integrated "design-to-object" systems. Our research suggests several steps to do this:

- **Increase industry's input into setting the agenda for federally funded manufacturing R&D.** There are a number of ways to increase industry involvement: Consult employers in the choice of new projects, make government laboratory funds contingent on finding private partners (as in some CRADA projects), and partially fund university research through grants passed through industry (as in ATP). Useful programs have begun in each of these areas, but too often, projects are still focused on building the most sophisticated, precise machines with too little attention on the mass market.

- **Create centers of excellence in manufacturing sciences.** Research in manufacturing systems requires a collection of expertise from a variety of different disciplines. Such centers of excellence can create spinoff benefits for surrounding industry and attract or create new firms. The federal government should encourage the formation of such centers across the country in a variety of forms including universities (such as currently exist at Purdue, Lehigh, and Carnegie-Mellon), NIST's Advanced Manufacturing Research Facility, and the DoE laboratories. There are currently promising programs in each of these areas. Our research indicates the need to assess the effectiveness to industry of the $6 billion government investment in the DoE national laboratories (an industry-led review group is now assessing the future of the labs), which thus far has yielded few tangible benefits for machine-tool makers and other firms.

- **Encourage more applied research.** Support the proposed launch of a U.S. Fraunhofer Institute or similar institutions devoted to applied research. There is currently little U.S. experience with this promising German model of contract-research centers that specialize in forging links between leading university centers of manufacturing engineering and firms.

- **Share the costs of high-risk industry-based research.** Continue direct support for industrial research, through such programs as R&D tax credits, ATP, and the
Technology Reinvestment Program. Consider modifying these programs to include more small companies, to strengthen ties between machine-tool makers, users, and external research institutes. Also place a greater emphasis on the users of the technology and the skills they will require.

- **Transfer technology through individuals.** The movement of highly trained personnel between laboratories is the most effective method of technology transfer. The government should use short-term placements, rotating fixed-term contracts, and other methods to encourage the exchange of research personnel between the public and private sectors. Such transfers are not currently an integral part of the existing programs.

### Other Vital Infrastructure Investments

While new product and process technologies are essential if U.S. machine-tool firms are to remain competitive, there is another set of factors—skills, capital, standard-setting—that firms require if they are to make efficient use of these new technologies. The role of the federal government in these areas is relatively limited, with most of the responsibility falling on state and local governments, networks, and the firms themselves. There are, however, a number of steps the federal government can take to create a more supportive infrastructure for machine-tool firms:

- Raise the skills of those entering the metalworking workforce by extending school-to-work initiatives in this sector, such as youth apprenticeship and cooperative education.

- Alter NSF funding criteria to increase the links between university engineering programs and industry, i.e., more exchange of students and faculty, greater emphasis on the human resource issues associated with implementing new technologies.

- Provide incentives for firms to invest in updating the skills of existing metalworking employees through such measures as the California Employment Training Panel and countercyclical retraining grants.

- Extend the initiative to create national skill standards in metalworking by creating a clearinghouse for best practices in education and training that can help diffuse the many innovations (e.g., interactive videos for operating a CNC lathe) that now often remain at a local level.

- Study the costs and benefits of matching the permanent incentives that foreign governments offer firms to invest in advanced manufacturing technologies, such as CNC and CAD/CAM.

- Strengthen standard-setting activities where needed, as for the Next Generation Controller, to include all of the main controller and machine-tool makers.
Encouraging Exports: Shift Market Focus from Domestic to Global Support

The discussion of alternative policy options has already outlined the main pros and cons of the VRAs. While there are arguments for a modified, temporary version of the VRAs, they appear to be outweighed by the costs protectionism imposes on machine-tool users, the lack of support for the policy from the industry, and the unintended negative consequences of the VRAs. This suggests that the preferred approach is: *Link the end of the VRAs to stepped-up enforcement of antidumping regulations so that foreign manufacturers do not try to compensate for the deep recessions in their own markets by flooding the United States with underpriced imports.*

In place of the VRAs, the government could adopt a series of measures designed to improve the export capacity of U.S. machine-tool makers:

- **Export controls**
  - Greatly streamline U.S. export licensing procedures.
  - Ensure that the regime which replaces the COCOM regulations confines export controls to the few machine tools with specialized defense applications that are not widely available on the world market.

- **Export promotion**
  - Work with U.S. industry associations to provide funds for machine-tool firm participation in foreign trade shows and conferences; establish shared sales centers in high-growth markets like the facility recently set up by the German metalworking employers' association in Singapore.
  - Decrease the transaction costs associated with export finance by extending the Export-Import Bank's program of bundling small firms' loans.

A BROADER LOOK AT SMALL- AND MEDIUM-SIZED MANUFACTURING ENTERPRISES

As noted previously, the U.S. machine-tool industry is primarily composed of SMEs. To the extent that these firms are representative of other smaller manufacturers, many of the policy options discussed above could provide a means of improving the competitiveness of SMEs generally. A rough comparison between the machine-tool industry and other manufacturing sectors indicates a number of similarities. One of the common features between the machine-tool industry and many others is that the market is increasingly global. Also, machine-tool makers are drawing from the same skill pool as other U.S. manufacturers and are facing similar problems of education and training. In addition, the arm's-length relationship between machine-tool manufacturers and users is typical of the relationships between many U.S. manufacturers and their suppliers. Likewise, many of the government regulations and programs we studied influence a far broader swath of the economy than the machine-tool industry.
The broad strategy for making the U.S. machine-tool industry a global player rests upon (1) creating regional networks of manufacturers, (2) investing in the manufacturing infrastructure, and (3) shifting trade policy from protectionism to export supports. The networking strategy is already proving relevant for a variety of U.S. SMEs. Furthermore, the application of the network concept to machine-tool firms depends upon the inclusion of their users, among other reasons, to encourage their adoption of the most competitive technologies.

Regarding the second part of the strategy, SMEs in general have had difficulty accessing federal programs and would benefit from the suggested mechanisms for increasing industry involvement. Finally, expanding into the global market will not be a panacea for all SMEs. There are industrial sectors where the domestic market is growing and provides ample market demand for products that would be considered competitive worldwide. However, the global focus that we recommend would directly benefit a large number of SMEs. Even being very conservative regarding an export strategy, it is difficult to envision how a more rational approach to export controls would hinder SMEs. In sum, our research did not consider whether the strategy that we record for U.S. machine-tool manufacturers is necessarily applicable across all SMEs. It did demonstrate, however, that elements from that strategy could benefit a much larger segment of the economy than the relatively small machine-tool sector.

CONCLUSION

Rapid technological and global economic changes have transformed the machine-tool industry in the last 15 years. U.S. machine-tool makers were slow to respond to the new competitive conditions. The result was a painful decade of downsizing that eliminated more than two-thirds of all American machine-tool firms and forced many of the remaining companies to restructure. There are some recent signs, however, that this long decline may have ended, as a surge in domestic demand for capital equipment in 1993 combined with the effects of restructuring has generated major improvements in industry performance.

The ability of U.S. machine-tool makers to sustain this recovery once the current surge in demand has subsided will depend, in part, on whether their internal restructuring can be matched by a transformation in the supporting infrastructure that provides the services that are beyond the capacity of individual firms. If the U.S. machine-tool industry is to compete effectively in the long term, our analysis suggests that new partnerships are needed among companies and between government and industry that focus on improving the inputs into the sector, turning these inputs into products, and marketing these products in the global marketplace.


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