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Technological capabilities and international competitiveness: A study on the machine tool industry

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TECHNOLOGICAL CAPABILITIES
AND INTERNATIONAL COMPETITIVENESS
A STUDY ON THE MACHINE TOOL INDUSTRY

by

EROL TAYMAZ

Submitted in partial fulfillment of the requirements
for the Degree of Doctor of Philosophy

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CASE WESTERN RESERVE UNIVERSITY

GRADUATE STUDIES

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TECHNOLOGICAL CAPABILITIES AND INTERNATIONAL COMPETITIVENESS

A STUDY ON THE MACHINE TOOL INDUSTRY

Abstract

by

EROL TAYMAZ

There is an intense debate on the role of the machine tool industry in industrial development, the effects of new flexible manufacturing technologies, and the implications of a weak domestic machine tool industry for the international competitiveness of domestic engineering industries. Although the debate continues over the role of a domestic machine tool industry, there is no empirical evidence shown to support or reject various hypotheses on those subjects. This study is aimed primarily at clarifying and statistically testing the relationships between the machine tool industry and the engineering industries.

This study has found empirical support for the following two hypotheses: 1) Recent emphasis on flexible automation has been catastrophic for the U.S. machine tool producers, since they have faced serious problems in adjusting their solid technological position in the manufacturing of mass production equipment towards the manufacturing of flexible automation equipment. The

U.S. engineering industries are negatively affected by the development of these new technologies by foreign firms because they tend to be supplied by the domestic machine tool producers for some time even though their products may be inferior to those of the foreign producers. 2) There are bidirectional 'Granger-causality' relations between the development of a domestic industry and the development of domestic engineering industries.

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CHAPTER 1

OVERVIEW OF THE PROBLEM

It is generally acknowledged that different sectors of an economy have different effects on productivity growth because the linkages between sectors can include the flow of information and technologies as well as transactions involving the purchase and sale of goods. The manufacturing sector, and within it, the engineering industries generate a disproportionate amount of the total technological change. There is empirical evidence to support these arguments (see Scherer's study (1982) on inter-industry technology flows). As Pavitt (1984: 359) shows in a study of sectoral patterns of technical change, mechanical engineering firms 'produce a relatively high proportion of their own process technology, but the main focus of their innovative activities is the production of product innovations for use in other sectors.' In accordance with this line of reasoning, especially following the classical article by Rosenberg, 'Technological Change in the Machine Tool Industry, 1840-1910' (Rosenberg, 1976: 9-31), a literature was formed to explain the vital role of the machine tool industry[1] in the development of new (metalworking) technologies. These studies suggest that this industry has played an important role in the development and diffusion of new technologies. Thus, the machine tool industry is considered as a 'nodal industry'. 'It is the transmission point of new technology to the rest of manufacturing industry' (Sciberras and Payne, 1985: 63). The following industry characteristics account for its role in the development and diffusion of new technologies.[2]

1) From the point of view of new technology development:

a) The machine tool industry uses all key metalworking technologies (foundry, forging, machining, heat treatment, etc.) in its production facilities. Moreover, the industry is characterized by its technological intensity and high-quality human resources. Compared to the average of all manufacturing industries, this industry is skilled-labor intensive. Therefore, the potential to solve technical problems is relatively highly developed in this industry since the alternative/substitutable technologies and the skilled-labor required in the

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[1] Machine tools are defined as power-driven, nonportable by hand, equipment that is used to cut, form, or shape metal. By the machine tool industry, we mean metalcutting and metalforming machine tool producer industries. It corresponds to Sections 3541 and 3542 in the Census Bureau's Standard Industrial Classification (SIC). By engineering industries, fabricated metal products, non-electrical machinery, electrical machinery, transportation equipment, and precision equipment industries are meant. They correspond to SIC 34-38.

[2] These arguments can be found in many publications. For a small sample, Rosenberg (1976; 1982), Beercheck (1979), UNIDO (1981), OECD (1970), NAE (1983), Sciberras and Payne (1985), and Succar (1988).

problem-solving process are abundant (technological capability).

b) The embodied technologies within machine tools are highly complex and this complexity always causes technological imbalances that provoke product improvements (technology push).

c) Machine tool user industries, that is, all engineering industries, require new machines and/or modifications of old machines to carry out new processes and to make old processes more efficient and these pressures of all engineering industries also provoke the development of new technologies (demand pull).

2) From the point of view of technology diffusion:

a) Since the machine tools have occupied the top position in the hierarchy of the pattern of interindustry relations (machine tools produce all other machines that produce all industrial goods), new technologies developed by this industry are diffused to the whole economy by using those machines which embody new technologies.

b) Since the machine tool industry is the center of technologically convergent metalworking processes, a new technology developed by this industry can easily be diffused to other metalworking industries which use similar manufacturing processes.

Although there is some causal evidence of the importance of these factors, there is no study that 'measures' the extent of technological change caused by those factors. But those factors are generally considered to be important and arguments go further on the importance of the well-being of a domestic machine tool industry.

Even though one can accept the arguments on the importance of the machine tool industry for generating and diffusing new technologies to the engineering industries and the importance of them for the international competitiveness, it is legitimate to ask the following question: Is it necessary to have a *domestic* machine tool industry to reap all the benefits of this industry? Many authors' answers are affirmative. The following factors are argued in favor of a domestic machine tool industry.

1) It is argued especially by people in the industry that this is a strategic industry in the sense that it is vital for military production in the case of a crisis, since it is a 'weapons-and-wealth producing industry' as defined by the editor of an industry journal (Weimer, 1987). This claim also was the basis of a petition by the National Machine Tool Builders' Association to impose import restrictions and has been repeated in many semi-official publications (NAE, 1983: 7, ITA, 1984: 84, and ITA, 1983: 64).

2) If this industry is technologically dynamic, and if the main driving force for firms to innovate is to secure (temporary) quasi-rents from their innovations, a domestic machine tool industry may capture some of the quasi-rents attached to innovations and may get super-normal profits from sales to foreign countries (Bruton, 1985:95). For example, it is asserted that Fanuc, the Japanese company that is the largest numerical control unit producer in the

world, sells its numerical control units to Europe at a much higher prices than those prevailing in Japan (Jacobsson, 1986:58).

3) The machine tool industry is considered an industry where income elasticity of demand is high during the early industrialization process. The growth rate of this industry may be greater than that of the manufacturing sector. Fransman (1986: 42) states that this consideration is among those factors that are used in the justification of industry selection process of MITI of Japan.

4) The most interesting case in favor of domestic machine tool industry comes from the distinctive relationships between machine tool producers and users. It is suggested that a close relationship between machine tool producers and users is necessary to satisfy the needs of users and that such a close relationship can be obtained only if producers and users are in the same geographical region and if there are no cultural and legal boundaries separating them.

The concentration of machine tool producers and users in certain regions and the fact that all successful machine tool firms started their development by first responding to their local markets can be considered to be evidence for these propositions. Some survey studies also support the proximity arguments. For example, O'Brien (1987: 30) affirms in his survey that 'in all producing locations (not just Japan) proximity is of vital importance to machine tool manufacturers - proximity to suppliers of high quality materials and components, proximity to a labor force to some extent trained by the machine tool industry itself, and proximity to buyers, many of whose orders are of a "custom-made" type. These are system requirements.'

Note that 'proximity' in these kinds of arguments is generally used to mean 'geographical', 'cultural' (linguistic), and 'legal' proximity. In this sense, proximity may create advantages to machine tool users and producers only by reducing transaction costs involved in the transportation of components and machines, and communications between the users and producers in the process of search, agreements, exchange of design information, etc. Possible sources of cost reductions obtained due to geographical and cultural/legal proximity will be analyzed in detail in Section 2.4.1.

Another type of 'proximity' which is probably more important than those stated above is the similarity of the manufacturing philosophies of the machine tool users and producers. Machine tool users tend to buy their equipment from those producers that can understand their approach to manufacturing and, consequently, that can respond to users' needs effectively in a short time without detailed contractual agreements. The importance of proximity in the understanding of manufacturing processes by machine tool users and producers is shown in the machine tool purchasing practices of Japanese automakers for their plants in the U.S. These firms would like to buy their machine tools from the Japanese producers although U.S. producers are (geographically) much closer than Japanese producers.

This type of proximity is established only as a result of long-term, stable relationships between machine tool users and producers, and is conditioned to some extent by the geographical and cultural/legal proximity, especially at the early stages of the development of the machine tool industry in a country. But, once established, the proximity in the manufacturing philosophies has a long-lasting effect on the relationships between machine tool users and producers. This subject will be explored in Chapter 2.

From the arguments on the importance of proximity of machine tool producers/users, it can be derived that those countries that have weak machine tool industry may suffer from the (temporary) lack of recent metalworking technologies. As Jones put it, 'countries which are dependent on importing the most advanced machine tools experience a certain delay in the diffusion of the latest machining technology' (Quoted by Sciberras and Payne, 1985: 64). This is also recognized by users themselves. In this context, M.G.Hasler, manager of machine tools and special studies in GM's corporate purchasing staff, said: 'We want to get the best production technology in the world in order to get the lowest possible cost of doing business. But, if you buy the very best from Japan, it has already been in Toyota Motors for two years, and, if you buy it from West Germany, it has already been in BMW for a year and a half.' (Quoted in AM, 1986: 45.)

Arguments in favor of a developed domestic machine tool industry are usually based on the assumptions about this industry's importance as a *source* of innovations in metalworking processes, as shown in some of the above mentioned studies. The assumptions on the sources of innovations have critical policy implications. For example, von Hippel (1988: 121) argues that user firms in the semiconductor industry are the sources of innovations in semiconductor equipment. Semiconductor equipment producers can build new equipment by incorporating innovations developed by users. Thus, given the importance of the geographical proximity of users and producers, both domestic semiconductor firms (users) and semiconductor equipment manufacturers (producers) can be better off only if the domestic user firms are the leading-edge innovators. As a result of this user predominance in the innovation process, the government support to the industry, if required, must target user firms instead of equipment producers.

A similar relationship appears between the engineering industries and the machine tool industry, too, because of the following reasons. First, user firms frequently dictate new machine tool designs, design modifications to currently available machine tools, and new processes (new machines) in accordance with the changes in their manufacturing requirements. Often these new ideas are initially conceptualized and applied by users themselves. Second, user firms are the sole source for the assessment of the quality of machine tools, i.e., they determine which designs and firms can survive in the evolutionary process of the development of machine tool technology. Third, an important portion of the change in machine tool technology is a result of the cumulative improvements in underlying technology by the adoption of new components supplied by the engineering industries to improve the properties of machine tools (cutting speed, accuracy, precision, etc.). By supplying new components to the machine tool industry, the engineering industries play an indirect role in the process of technological development generated by the machine tool industry itself.

The existence of leading-edge machine tool users is not a sufficient, although perhaps necessary, condition for the domestic generation of new metalworking technologies. In addition to this factor, first, domestic machine tool producers must have technological capabilities that allow them to be responsive to the needs of users and to exploit the potentials of new components produced by the engineering industries. Second, the institutional structures and dynamics must be established in such a way that the activities related with metalworking (design and development of metalworking machinery, their manufacturing, system implementation, startup and debugging, and using systems in manufacturing) can be economically coordinated. The main focus of this study is on the effects of the domestic machine tool industry on the engineering industries. Accordingly, technological capabilities of the domestic machine tool producers, and the interrelationships between machine tool users and producers will be analyzed in detail in the following chapters. The problem of the sources of innovative ideas will not be specifically addressed although it should be stressed that this problem has serious policy implications.

Among the arguments summarized above, the first one on strategic/-military importance of the machine tool industry will not be considered in this study since it is not in the realm of economics. The second argument is related to the existence of innovating firms and some specific market conditions. The third one is true only for some stages of economic development. For example, it is difficult to claim that this industry is a growth industry in many developed countries after the 1960s. Only the last argument which is also more important for understanding the specific characteristics of the technological development process in machine tools could be the subject matter of research. Thus, in this study, one of the areas of interest will be on the interrelationships between machine tool producers/users and the effects of proximity on these relations. Since there is no empirical study on this subject, an econometric model will be developed and tested to determine the effects of a weak domestic machine tool industry on the international competitiveness of user industries.

The policy implications of those arguments on the relationship between the domestic machine tool industry and user industries are not immediately obvious since the cost side of any intervention (subsidy costs, costs of import restrictions, etc., depending on the policies adopted) should also be evaluated. Although some researchers justify state intervention to develop this industry on the basis of these arguments, sound empirical evidence is generally absent.

For example, in one of the best recent studies on this industry, Jacobsson (1986) used only the export performance on the benefit side, and nothing at all on the cost side of intervention. The lack of evidence could be expected since it is almost impossible to measure all the benefits and costs of state intervention in this industry. Moreover, the determination and implementation of specific policies may be practically impossible in the era of multinational corporations that blur the national boundaries to a large extent and make it difficult to evaluate firm and industry responses. Thus the policies to help the domestic machine tool industry will not be specifically studied.

The purpose of this study is to contribute to the literature on the capital goods industries by analyzing the effects of new (flexible) manufacturing technologies, the implications of a weak domestic machine tool industry for the international competitiveness of domestic engineering industries, and the role of the machine tool industry in industrial development. The study is focused empirically on the effects of the relative decline in the technological capabilities of the U.S. machine tool industry after 1975 on the international competitiveness of U.S. machine tool users, i.e., U.S. engineering industries, and on the 'Granger-causality relations between the development of domestic machine tool and engineering industries in the Federal Republic of Germany (FRG), Japan, Sweden, and the U.S.

The thesis is organized in the following order. In Chapter 2, a conceptual framework is developed in which the characteristics of the machine tool design and development process, and the implications of the specific relations between machine tool users and producers are analyzed. By using this framework, the potential benefits of a domestic machine tool industry are explored. Two main hypotheses on the relationships between the machine tool industry and the engineering industries are developed. Chapter 3 contains an analysis of manufacturing systems[3] in the engineering industries. Major manufacturing systems and their correlations with specific machine tool types are found on the basis of U.S. machine tool stock data, as interpreted through factor analysis. Chapter 4 covers the recent changes in the use of manufacturing systems, and the competitive position of the U.S. producers in various segments of machine tools. The framework developed in Chapter 2 is used to explain these changes and the results of the analysis on the relationships between manufacturing systems and machine tool types (Chapter 3) let us derive conclusions on manufacturing systems on the basis of machine tool data in Chapter 4. The focus of this chapter is on two arguments: i) recent changes in machine tool technology are toward flexible manufacturing, and ii) U.S. machine tool producers are relatively less competitive in these fields because of their long commitment to mass production technologies. In Chapter 5, the effect of the deterioration in the technological capabilities of the U.S. machine tool industry on the international competitiveness of the

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[3] Metalworking is the most significant process used in the production of engineering goods. Since our interest is focused on the engineering industries, 'manufacturing systems' and 'metalworking systems' are mostly used in the same meaning throughout this study.

domestic engineering industries is tested by using regression analysis. This test is preceded by a complementary test of the hypothesis about the inertia in the relations between machine tool users and producers. Chapter 6 contains tests of causality relations between the development of machine tool and engineering industries for the Federal Republic of Germany (FRG), Japan, Sweden, and the U.S. Granger's concept of causality is applied in these causality tests. A brief summary of principal findings of this thesis, major caveats of techniques used in various statistical tests, and some directions for further research are reviewed in Chapter 7.

CHAPTER 2

CONCEPTUAL FRAMEWORK

2.1. Introduction

The overview of the problem of the relationships between the machine tool industry and the engineering industries in the preceding chapter shows that it is necessary to study the process of technological change in machine tools for a better understanding of the role of the machine tool industry.

The question of the essential characteristics of technological change is somewhat too broad to be analyzed since there are significant inter-industry differences (Nelson, 1987: 7). The mechanisms and properties of technological change should be studied separately to understand recent changes in this industry and specific interactions between the machine tool industry and the engineering industries. Thus a conceptual framework will be developed in this chapter to analyze the specific characteristics of the evolution of machine tool technology, its impact on user industries, and the interconnections between various economic agents in this process. Section 2.2 focuses on the characteristics of change in machine tool technology in relation to the technological capabilities of machine tool producers, and institutional dynamics that coordinates those activities in the design and development process. The relationship between machine tool users and producers which constitutes the basic link in the diffusion of new technologies is studied in Section 2.3. The 'benefits' of the development of a domestic machine tool industry (the effects of domestic technological capabilities in machine tool technology on the international competitiveness of the engineering industries) is the subject matter of Section 2.4. The last section summarizes the basic hypotheses derived from this conceptual framework.

2.2. Design and Development Process

The first step toward the conceptualization of technological change in machine tools is an understanding of the process of creation of new knowledge (information) on machine tools and processes. Thus, the characteristics of products of this industry and the creation of new knowledge are studied in this section. Before the analysis, two specific characteristics of this industry are worth mentioning.

In economics, the literature on technological change is mainly focused on research and development (R&D). It is generally accepted that R&D activities are the major source of technological development. In this sense, the share of R&D personnel in total employment or the ratio of R&D expenditures to total sales are indispensable variables to be used to measure the technological level (and, even, technological progressiveness) of firms and/or industries. But formal R&D does not play a major role in the machine tool industry. Compared to other technologically dynamic industries, the share of R&D expenditures in total sales is very low. For example, in Japan, R&D costs-sales ratio for the machine tool industry was less than 1.3% in 1985 whereas same ratio for the electrical machinery and all manufacturing industries were 5% and 2.3%, respectively. And, more importantly, there is no clear trend for an increase in the R&D costs-sales ratio for the machine tool industry in the last couple of years, whereas this ratio is rapidly increasing for other industries (MEM, 1989: 27). It is the same in the U.S. machine tool industry, too. (For R&D costs-sales ratios of major U.S. producers, see Business Week, 1984: 73.) But the low level of R&D costs-sales ratio does not mean that the machine tool industry is technologically static. On the contrary, R&D expenditures do not measure the industry's innovative capabilities since it is a kind of industry that fits into the case described by Nelson in a general context.[1] The technological development in the machine

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[1] Nelson considers two types of industries in relation to the role of R&D. In the first case

> ...innovative R and D in the industry consists largely of exploiting new ideas created by outside science, or making use of a flow of new materials and components created by supplying industries. In this case low innovative R and D in the industry itself would result in a jerkier time path of best practice and somewhat lower overall track than were internal innovation oriented R and D higher, but not necessarily a lower rate of growth of productivity. [Recall that these are the characteristics of the machine tool industry.] On the other hand, if technical change in the industry results largely from its own internal R and D and today's R and D efforts build on yesterday's R and D successes, a lower R and D spending might be expected to translate into a slower rate of advance of best and average practice technology. (Nelson, 1987: 42-43.)

Similarly, Pavitt (1984: 370) states that 'R&D statistics do not measure two important sources of technical change: the production engineering departments of production intensive firms, and the design and development activities of small and specialised suppliers of production equipment'. These activities are the major innovative activities in the machine tool industry.

tool industry consists largely of ‘exploiting new ideas created by outside science, or making use of a flow of new materials and components created by supplying industries’ (Nelson, 1987: 42). The continuous, minor design and development activities are the main sources of major changes.

The second important specific characteristic of machine tool technology comes from its top position in the interindustry relations. There is not any clear distinction between process and product innovation in this industry. Any process (and, to a lesser extent, any product) innovation is also a potential product (process) innovation since the essential manufacturing equipment used in this industry are machine tools. Thus, for example, one of the most sophisticated flexible manufacturing systems (FMS)[2] produced by and installed in Yamazaki Machinery (now Yamazaki Mazak) (Usui, 1984) is both a product and process innovation for this company. (This duality of innovative activity in machine tools, as will be seen below, has important implications for learning processes and competitiveness of machine tool producers.) For this reason, the following description of machine tools is also a characterization of process equipment employed in this industry.

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[2] FMS is defined by the Computerized Integrated Manufacturing Section of Arthur D.Little, Inc. as follows: ‘A group of CNC [computer numerical control] machine tools linked by an automated materials handling system, whose operation is integrated by supervisory computer control. Integral to an FMS is the capability to handle any member of similar families of parts in random order’. (Quoted by Young and Greene, 1986: 8.)

2.2.1. Product

Any manufacturing system has the following components (Miller, 1985: 33):

* A set of tools for processing materials;

* A means for moving materials from one tool to another;

* A means for controlling and monitoring the action of the tools and the movement of materials.

The products used in the engineering industries that correspond to those groups are i) machine tools, ii) materials handling equipment (conveyors, automatically guided vehicles, industrial robots, etc.), and iii) various types of control systems (human-control, cam-controls, programmable controllers, computers, etc.). Note that all these components are not produced in a single industry.

The basic component of the metalworking process is machine tools since they perform the function that is the raison d'être of the transformation process, i.e. metalworking. Moreover, except in the case of highly integrated production systems, material transfer and control functions are performed manually. That is, machine tools are the most important type of equipment in the bulk of manufacturing systems currently used. Even in the most integrated manufacturing systems such as FMSs, machine tools generally constitute the largest share in total system cost. For this reason, in the production of those types of manufacturing systems, machine tool firms are the main system-builders. Thus a more detailed description of machine tools is necessary.

Machine tool types are defined by the specific machining processes performed such as turning, milling, boring, grinding, etc. For example, a lathe is a machine tool that mainly performs turning operations. Machine tools may also be classified according to their production requirements (standard/ custom made), forms of combination with other machinery (stand alone/ system), control systems (conventional/ NC) and range of operations they can perform (general-purpose/ special purpose). These groups and some examples for each group are given in Figure 2.1.

This description shows that the machine tool industry has highly differentiated products. But in spite of this end-product richness there is a relatively small number of common machining operations. All machine tools use similar components and have similar technical problems. 'It is because these processes and problems became common to the production of a wide range of disparate commodities that industries which were apparently unrelated from the point of view of the nature and uses of the final product became very closely related (technologically convergent) on a technological basis.' (Rosenberg, 1976: 16) This phenomenon, defined as 'technological convergence', is a peculiar characteristic of machine tools.[3]

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[3] Technological convergence can occur in other industries as well. For the case of electronics, see Teubal, Halevi, and Tsiddon (1986).

Figure 2.1 Examples of products according to defined classifications

	General-purpose		Special-purpose	
	Standard	Custom	Standard	Custom
Conventional				
* Stand-alone	Turret lathes, milling machines	Longer bed lathes	Jig grinder	
* Systems				Transfer lines
CNC				
* Stand-alone	CNC lathes, machining centers	Larger bed and taller head machhining centers	CNC jig borers	High precision, extended tool magazine machining centers
* Systems	Flexible manuf. cell (FMC)	Flexible manuf. systems (FMS)	CNC gear cutting machines with robot feed	Versatile transfer lines

Source: Sciberras and Payne, 1985: 2.

Finally, we have to mention components of machine tools. There are three types of components in any machine tool: i) small standard parts and consumables (high-tensile screws and bolts, anti-friction ball bearings, oil seals, cutting fluids, paint, etc.), ii) pre-assembled (proprietary) components (electric motors, servo-motors, electric controls, etc.), and iii) machine tool-specific components (gear boxes, casting beds, ballscrews, tool holders, spindles, etc.). The former two sets of components are purchased from other engineering industries except electronic control units which are, in some cases, manufactured in-house. There is almost no research and development activity for these components. The machine tool industry is completely dependent on other industries for the supply and development of these components. This dependence on the sophistication of pre-assembled components is one of the major links of technological diffusion from the engineering industries to the machine tool industry.

The competitive edge of machine tool producers lies in the non-standard, machine tool-specific components which are generally designed in-house. Manufacturing and processing of these components are done in-house as well as by subcontracting to other (specialist) firms (Barrar, 1987). Although the design (e.g., dimensioning) of these components can be easily copied by other producers[4], an important part of information concerning these parts (and the machine tool itself) may not be easily transferable because of some special processing operations (e.g., heat treatment), and performance characteristics.

2.2.2. Technology and the coordination of activities

The activities undertaken during the implementation of a metalworking system (design and development of machine tools and other equipment, their

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[4] Patenting may be the best (or only) way of protecting a particular design.

production, system integration, start-up and debugging) should be coordinated by a definite mechanism to obtain desired results. There are three different types of coordination mechanism. First, some activities may be coordinated by the 'organization', i.e., the 'entrepreneur' who directs production. Second, some activities may be coordinated by the interaction of firms in markets as a result of price movements, etc. There is also a third type of coordination defined by Imai (1989) as 'network organization'. It implies interactions between firms without an explicit market transaction.

The boundaries of a firm in the machine tool industry are drawn by the activities coordinated by the firm. As in any other industry the activities coordinated by a machine tool firm are determined by the extent and growth rate of the market being served, the history of the firm (path of development), manufacturing technology employed (asset specificity, etc.), and the development level of supplier industries, i.e., level of specialization and the possibilities of sub-contracting (see Langlois, 1989). Thus, a firm can be defined by the extent and types of activities under its coordination. But besides a set of coordinated activities, a firm is also defined by a set of specific information on technology concerning its products and manufacturing processes since some elements of information held by the firm are unique to itself.

It is important to distinguish between two different aspects of technology. 'On the one hand a technology consists of a body of knowledge', which Nelson (1987: 75) calls generic,

> in the form of a number of generalizations about how things work, key variables influencing performance, the nature of the currently binding constraints and approaches to pushing these back, widely applicable problem solving heuristics, etcetera. ... On the other hand, a technology also comprises a collection of specific ways of doing things, as artifacts, that are known to be effective in achieving their ends if performed with reasonable skill in the appropriate context. These comprise the currently operative 'techniques' of a technology.

This second aspect of technology, resulting from accumulated experience in design, production and investment activities, is mostly tacit and cumulative in nature and retained by 'individual teams of specialized personnel' (Rosenberg and Frischtak, 1985: vii). In the case of the machine tool industry, generic knowledge is codified in mechanical and electrical engineering and material sciences. It is generally available in technical publications, operating manuals of components, etc., without any significant cost. On the other hand, some specific manufacturing operations (such as heat treatment that cannot be obtained by 'reverse engineering'), the characteristics and performance properties of product designs, etc., are firm-specific and can not be easily imitated by other firms.

An important part of firm-specific knowledge and design capabilities in the machine tool industry comes from two processes: learning by doing and learning by using. The former process takes place at the manufacturing stage, either in the manufacturing of prototypes during the design process or in the manufacturing of products that have already been designed. Learning at this stage consists mainly of developing skills for manufacturing and, to a lesser degree, design modifications primarily related to dimensioning, component selection, etc. Learning by doing, of course, may lead to reductions in machine tool production costs. (For early evidence on the cost reductions as a function of cumulative output, see Hirsch, 1952 and 1956.) Here, our emphasis is on the development of design capabilities within a firm as a result of learning by doing. Note that, in both cases, learning by doing may lead to economies of scale that have important consequences as shown in Section 2.3.

Learning by using, probably more important than learning by doing for machine tools, takes place as a result of products' utilization by the final user. This learning effect occurs because of the fact that the performance characteristics of a machine tool can not be understood until after prolonged experience with it. There may be technical errors and mistakes in new designs since the design process is always faced with uncertainties concerning engineering properties of materials, the complicated interactions of components, predictions on design criteria, etc. As Rosenberg stated (1982: 122), 'for a range of products involving complex, interdependent components or materials that will be subject to varied or prolonged stress in extreme environments, the outcome of the interaction of these parts can not be precisely predicted. In this sense, we are dealing with performance characteristics that specific knowledge or techniques cannot predict very accurately. The performance of these products, therefore, is highly uncertain.' This uncertainty can be partly reduced by simulated experiments, etc., but many significant product characteristics are revealed only after intensive use. As 'the proof of the pudding is in the eating, the proof of a design is in the use of the product. Evolutionary design waits for the evidence which use reveals. But the lapse between the original bold and primitive essay and the final sophisticated version may be many generations' (Asimow, 1962: 31). In the case of manufacturing *system* design such as FMSs, *ex post* design problems are explicitly recognized. 6-10 months of debugging period after installation is not uncommon for these systems.

Learning by using may lead to reductions in production costs and/or modifications for improved designs. The first designs of machine tools to be produced for new markets or for reliability sensitive markets are generally done very cautiously to secure the entry and initial position in these markets. These first designs may overfulfill their specification on average. Gradual design modifications to reduce production costs may be accomplished by relaxing (unnecessarily) tight tolerances, easing of the less-critical specifications, etc. Later on, problems of old designs may permit improvements in design or operation/maintenance standards. Because of the importance of learning by using, machine tool producers need to get feedback from users. This is an important factor that may necessitate non-market information flows.[5] Recent changes in metalworking technologies tend to increase the complexity of manufacturing systems via increasing sophistication of production equipment and their raised integration level. Thus, learning by doing and using processes may be expected to be more important as a result of these new technologies.

In brief, a firm can be characterized by its technological position and capabilities. The firm's technological position can be mapped into the activities performed during the implementation of metalworking systems. Similarly, technological capabilities (the products and processes that can be produced/performed by the firm at a satisfactory economic level) can also be characterized by a 'technology matrix', the dimensions of which are various technological characteristics of products/processes. Recall that the technological position and capabilities of a firm are chosen by the firm itself in the long run. Firms may change their positions and enhance their capabilities in a specific direction by a piecemeal process of learning. As Jaffe (1986: 986) says in a general context, 'the technological position of firms can be brought about only slowly. Expertise in various areas is not easily acquired, and goodwill and reputation in product markets represent sunk costs that

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[5] Some machine tool producers can use their own machine tools in their manufacturing facilities. The importance of internalizing learning by using in this way is recognized in a survey of machine tool producers. In the same survey, it is claimed that Japanese machine tool producers enjoy easily these learning benefits due to their integrated company structures (see Sciberras and Payne, 1985: 29, 44, 64). See also Fransman (1986b: 1385) and Sciberras (1986: 9) for machine tools, ITA (1985: 33) for robots, and ITA (1985: 85) for FMS cases.

make jumping costly.'

A firm, given its objectives, searches for an appropriate product/market combination (design, development and production decisions) in light of the following considerations:

1) Its technological capabilities. Since technological capabilities (the range of firm-specific information and information channels to the 'technology shelf' in the industry) are determined to a large extent by the firm's previous activities, the various search areas may be expected to be close to the present position of the firm. (Stewart, 1985: 25)

2) Expected changes in technology and markets. Since each new alternative activity will increase the firm's technological capabilities in a certain direction, the firm tends to choose those alternatives that are in connection with expected technological development (changes in technological opportunities) to secure its future technological position.

3) The characteristics of markets its wants to serve.

4) Financial leverage of the firm and its financial sources.

This search process of machine tool suppliers for new design concepts and appropriate market/product combinations is determined by the strategy of the firm. Basic strategies followed in this industry have been analyzed in detail (see Carlsson, 1986 and Jacobsson, 1986: 66-79). Here, two major properties of this search process need to be emphasized. First, as in other decision-making processes, this search process is carried out as a matter of 'routine' (Nelson and Winter, 1982). Prevailing routines in a firm can be understood as having arisen through a series of past actions (including past routines, probabilistic outcomes of past searches, reactions of competitors, etc.) (Nelson, 1987: 32). Second, as a result of the routines of the search process and the path-dependent character of the firm's technological position, this search process leads to cumulative decisions in the sense that firms tend to search in the vicinity of their present technological and market positions. This subject that also includes the decisions of machine tool users will be explored in detail in the following section.

As a result of firm-specific knowledge obtained through an active learning process in production involving the use of machine tools, and costly design and development activities, information and technologies on metalworking operations are dispersed among machine tool firms. Most of the knowledge used by machine tool producers in their design and development processes is not easily transferable; it is accumulated within the firm along its technological paths and can only be appropriated by other firms that develop similar technological capabilities. Rosenberg and Frischtak (1985: viii) summarize this fact as follows.

> Insofar as technology is conceived as firm-specific information concerning the characteristics and performance properties of production processes and product design, and to the extent that it is tacit and cumulative in nature, the transfer of technology is not as easy as the purchase of a capital good or the acquisition

> of its blueprint. It involves positive and significant resource costs, reflecting the difficult task of replicating knowledge across the boundaries of firms and nations; recipients would normally be obliged to devote substantial resources to assimilate, adapt, and improve upon the original technology.

2.3. The Inertia in the Relationships Between Machine Tool Users and Producers

As stated above, the search process of machine tool suppliers operates according to a definite set of decision rules. In a similar way, the investment decisions (purchasing of new machine tools) by user firms are also carried out by some definite routines. These routines (and some other factors too) operate in such a way that, once established, the relationships between machine tool producers and users/markets tend to gain an inertia against any change. In other words, well-established connections resist any new producer/user relations. (Of course, the relative strength of resistance depends upon many factors.) The following determinants can be responsible for this phenomenon.

1) User firms also benefit from 'learning by using'. This process for users means learning the true performance of a machine tool. For example, Texas Instruments (TI), a massive machine tool user, keeps computerized records of machine maintenance calls and of machine control failures. TI is instituting a policy of requesting bids only from average or better performers

according to TI's *own records*, with reasonable exceptions, such as machines from vendors that are on an improving trend (Emerson, 1986: 74). By this 'routine', TI sticks with 'satisfactory' machine tool builders and will not consider unknown producers' machines unless they earn a good reputation elsewhere or offer more than normal benefits. Large machine tool users generally have this type of formal procedures to keep track of the performance of each machine tool used in their manufacturing facilities. This process works for small users, where scale economies for search are important, mainly through experience of other users in the same region ('demonstration effects')[6]. This factor also explains the temporary avoidance by small machine tool users of new, and therefore unproven, machine tools and technologies. Generally large firms that can disperse risks undertake investment in new technologies.

2) User firms are inclined to use the same producers' machine tools as long as they seem to be satisfactory since, in this way, they capitalize on their familiarity in operations and maintenance of old machine tools and systems and keep smaller inventory of similar, interchangeable tools and components.

3) Long-term, continuous relations with users are also beneficial for producers to obtain the benefits of 'learning by using' as explained above. Moreover, a long-term relation between users and producers creates a

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[6] For this reason, users tend to purchase machine tool from 'proven' producers. According to Rendeiro (1985: 66), 70% of machine tools in the U.S. are bought on the basis of brand effects.

common pull of information regarding the specific (and sometimes proprietary) technologies developed for the users' manufacturing needs. This common asset may favor the consecutive relationships.

In addition to these factors, there are some other reasons for producers to adhere to their relations with certain market segments. The first reason is a result of a cumulative process of developing technological capabilities. Machine tool firm's new products are to be within the technological capabilities of the firm, i.e., relatively technologically close to its earlier products. The second reason is due to economies of scale in marketing, sales and after-sales services which is the major source of scale economies in NC[7] lathe production according to Jacobsson (1986: 98). These scale economies originate from the fact that the first sale of a machine tool to a new customer generally involves a much greater sales effort (relative to repeat sales) and after-sales services (inventories of spare parts, engineering support, etc., for a specific market) which involve high fixed costs. That is, it is easier to maintain a particular market segment than to create it. The last factor is a result of the establishment of specific modes of behavior (including implicit agreements) with users, suppliers, etc., in the course of long-term relationships. For example, O'Brien (1987: 30) argues that one of the obstacles to direct foreign investment in the U.S. by Japanese machine tool

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[7] Hereafter, numerical(ly) control(led) (NC) is used to mean all NC technologies applied to machine tools including NC proper, computerized NC (CNC), etc.

producers is the necessity of shifts from their well-established modes of operation. This type of inertia between producers and users may be important to explain the lack of some users and countries in the adoption of new technologies and manufacturing systems in the course of rapid technological changes triggered by other producers (in other countries).

The 'inertia' in the relationships between machine tool users and producers, and the difficulties in the imitation of firm-specific knowledge have been clearly shown in the case of direct foreign investment in the U.S. by Japanese automakers. These companies would like to buy their production equipment from the Japanese producers but the voluntary restraint agreement that imposes quantity restrictions on machine tool imports from Japan severely restricts their ability to obtain Japanese tools. Even though the U.S. machine tool producers are in a relatively better position in the supply of special-purpose machine tools, Japanese automakers 'would in their hearts like to avoid to procure U.S. tools as much as possible', since, as a Japanese industry journal claims (MEM, 1988b: 36-37),

> the Japanese machine tool builders have a full understanding of Toyota-concept, Nissan-concept, and other unique production philosophies of the automakers and have the knowhow and technical expertise to supply machinery and equipment meeting the same. The strength of the Japanese auto industry lies in the 'Japanese-style' production control and production technology, which differ from those of both the US and Western Europe.

Use of Japanese machine tools is part of this.

For obvious reasons, machine tool firms start their activities by first responding to the 'local' markets, After they acquire sufficient technical expertise, marketing capabilities and capital, they look for distant markets. This initial development initiated by responding to the needs of local users may have a long-lasting effect on machine tool firms since the accumulation of specific skills and knowledge in the design and production of a particular type of machinery will help the firm to move toward a specific direction for future development. In this manner, it may be possible to identify a machine tool industry by the structure and development of the engineering industries in that country. For example, the reputation of precision Swiss machine tools and the so-called 'Swiss-type' screw machines reflect to a large extent the legacy of the small, precise machining requirements in the Swiss engineering industries (especially mechanical clock and watch production). In a similar way, U.S. machine tool producers have excelled in the manufacturing of mass production equipment, because in the U.S., 'machine tool development was from the very beginning linked with the "American System" of manufacture of interchangeable parts, specialization, standardization, and eventually mechanization and mass production' (Carlsson, 1984: 106). The early development of NC machine tools in the U.S. by the Army has led the U.S. producers to accumulate technological capabilities in the design and production of robust, large NC machine tools according to the requirements of military production (Noble, 1984 and DiFilippo, 1986). But this development has also caused the relative neglect of small, cheaper, general purpose NC machine tools in the U.S. These examples show the prominence of path dependency in the development of technological capabilities in this industry.

2.4. The Benefits of Domestic Machine Tool Industry

In the preceding sections, the tacitness of technical expertise in machine tool technology, the difficulties in the availability and imitability of knowledge, its dispersion among firms, and the specific routines of search behavior between machine tool users and producers arising from imperfect understanding of machine performance, etc., were analyzed. This analysis suggests that the successful use of knowledge concerning machine tool technology is to a large extent dependent upon the possibilities of firms and countries to develop their own technological capabilities. Thus, the benefits of domestic machine tool industry, if any, should be related to the industry's contributions to the development of technological capabilities of domestic engineering (including its own) firms. This problem, therefore, can be reduced to the effects of proximity on the inter-industry (machine tool users/producers) and intra-industry (machine tool producers/producers) information flows. Although all of them are closely interrelated and intertwined, there are three different sets of factors that may create benefits from the existence of a well-developed domestic machine tool industry: i) effects of proximity on transaction costs, ii) (learning by doing) externalities, and iii) interdependence of closely related metalworking activities.

2.4.1. Transaction costs

The most obvious and often cited effect of geographical and cultural/legal proximity between machine tool producers and users is the relative changes in the transaction costs (transportation and communication). The importance of geographical and cultural/legal proximity and its effects come from the following facts.

1) There may be differences in the required machine design in each country because of the differences in factor endowments, legal restrictions, etc. Thus, machine tools should be design and produced according to local conditions for an effective use. (For example, Rosenberg (1976) gives a detailed account of changes in the design of woodworking machinery by local producers in accordance with the abundant wood supply in the 19th century U.S.) It is argued that distant machinery suppliers who lack the understanding of local conditions and requirements cannot supply appropriate machinery. Although this argument is generally used for the development of machinery sector in the less developed countries (for an evaluation, see Pack, 1981), it has been recently used for the defense of the U.S. machine tool industry (for example, see Industry Week, 1984: 64).

2) For the special-purpose machine tools (generally demanded by large users), 'users need to have located nearby a machine tool design and development capability and engineering support so they can easily and frequently discuss their needs. Reliance on imports from distant suppliers would make the necessary access much more difficult.' (Sciberras and Payne, 1985: 64) There is some anecdotal evidence that supports this hypothesis. (For an example, a German flexible manufacturing module (FMM) producer who does not sell to distant markets because of this reason, see Jacobsson, 1986: 70.) Moreover, users may learn about what they really want or need only in a close relationship with producers.

3) Users (especially small companies) rely on after-sales services for an effective use of machine tools. A strong after-sales service requires proximity to users.

4) For small users, the cost of information search is relatively high. Hence they tend to use machine tools produced in geographically and culturally close regions (Jacobsson, 1986: 57).

5) Feedback from users on machine tool performance is critical for new, improved machine designs since the process identified by Rosenberg as 'learning by using' offers one of the most accurate ways to assess machine tool performance. These feedbacks will be more intense if users and producers are in a close proximity (Bruton, 1985: 95).

6) Finally, as a result of the above-mentioned factors, it is claimed that

the latest machine tool technology is developed in response to the needs of 'close' users and it is transferred to other users with a considerable time lag. Thus, countries which do not have technological capabilities in their machine tool firms may have to import the advanced machine tools with a certain delay. Or, the National Academy of Engineering (1983: 8) puts it, '[s]hould the American [machine tool] industry not take the lead in the development of the newest innovation in machine tooling, the prospects exist that important advances in manufacturing technology for many industries might be significantly delayed, or escape development at all, in this country relative to its overseas competitors'.

Although it is almost impossible to quantify the effects of these factors, there is some evidence that may show their existence. First, newcomers into machine tool manufacturing start with supplying their local markets. For example, Amsden (1985) shows that the machine tool industry of Taiwan, which is currently highly export oriented, came into existence by supplying markets in Taiwan and Southeast Asia. After it reached a certain level of maturity, it expanded its exports to the developed countries, especially the U.S. Second, in those countries whose machine tool industries have been faced with very intense foreign competition in recent years, the least affected firms are those who produce special-purpose machine tools. Note that this segment of the machine tool industry requires the closest interaction between users and producers. The position of the U.K. and U.S. producers can be given as examples. 'UK firms have been relatively successful in special-purpose machine tool segments in the past. Because they were locally situated the UK firms have had an advantage over foreign competitors in serving aerospace and automobile customers. These users have required proximity to machine tool designers to meet their custom engineering needs' (Sciberras and Payne, 1985: 19). The same observation is valid for the U.S. For example, the import penetration ratio (M/Q+M-X)[8] for station-type machines (which are the major part of the special-purpose machines) for the U.S. in 1986 was only 3.95% whereas same ratio for all machine tool total was 51.1%.[9] And finally, one of the major reasons for direct foreign investment in this industry is to be in a close proximity to users for a better ability of tailor-made design, responsiveness, etc. (O'Brien, 1987: 31). In a survey study, von Pfeil (1985) has also found this among the most important factors affecting the decision of German machinery producers to invest in the U.S.

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8. Throughout this thesis, Q, X, and M are used to denote 'production', 'exports', and 'imports'.

9. For similar reasons, the export-sales ratio (X/Q) of station-type machines for the same year was .84%, and for machine tool total 21.5%. These ratios, of course, do not mean that the U.S. station-type machine producers are internationally competitive. (Indeed, net exports of station-type machines in 1986 was negative.) They only show that this segment of the industry is better sealed off from the entrance of foreign competitors just because of the requirements of close proximity to users.

2.4.2. External economies

The types of benefits of domestic machine tool industry as summarized above basically occur due to transaction costs in the information transfer that is market-mediated, and are generally paid for by the user firms. This industry may also create some external economies, i.e., benefits which are not paid for by users as a result of information transfer without explicit market transactions. As Jacobsson (1986: 227) stated, 'there are reasons to believe that there are external economies associated with having a well-functioning machine tool industry. In other words, there may be a positive relationship between the performance of the machine tool industry and the performance of the engineering industries as a whole.'

The machine tool industry can generate some positive external economies to other metalworking industries in the form of manpower training. Since it is supposed that the machine tool industry needs high-quality manpower and embodies all major metalworking techniques, it may offer unique learning opportunities. Moreover, as Bruton claimed (1985: 95), as a branch of the capital goods sector the machine tool industry 'contributes to the creation of a category of people who not only have certain specific skills, but, more importantly, have a certain kind of attitude. This attitude may be characterized as a confidence in the profitability of search, the belief that technical and economic problems can be overcome.' Labor mobility within regional boundaries helps other industries to satisfy their skill requirements.

Note that this factor, if significant, can help the machine tool industry in the same way.

Another source of externalities created by the machine tool industry comes from its position as the center of technologically convergent metalworking technologies (see Rosenberg, 1976 and Succar, 1988). Thus, the machine tool industry may play a role as an intermediary between seemingly unrelated industries in the process of the diffusion of metalworking technologies, in addition to its role in the creation of new technologies. These technologies may include 'hardware' (product) innovations as well as improvements in 'software' (management practices, production organization, etc.). Recall that the type of information transfer implied here includes only those informal, non-market mediated flows that occur by the 'demonstration effects', plant visits, informal meetings, availability of products in the markets, etc. The proximity of economic agents may promote these types of information flows.

2.4.3 Interdependence of activities

The most important benefit of a domestic machine tool industry comes from the interdependencies in metalworking activities. 'Interdependent' activities are those in a set of activities that may not be profitable when they are undertaken separately, but that can become profitable when they are undertaken together (or in a specific sequence in time).[10] The importance of interdependencies lies in their effects on the necessity of non-market mediated information flows to obtain the benefits (opportunities) hidden beneath interdependencies. There are two different types of interdependencies.

1) *Technological interdependencies* are the result of the fact that the whole process of technological change may not fit into 'the often -and increasingly- artificial boundaries of the firm' (Rosenberg, 1982: 235). This is especially true for the machine tool technology because of the highly specialized character of machine tool firms and also other firms that supply complementary equipment (robots, materials handling equipment, measuring equipment, etc.) for metalworking processes, and user/producer relationships in this field.

The design and development of a new product/process may have important economic effects not only 'at the point of immediate application' but also in vertically and horizontally related activities because of technological complementarities and technological convergence ('ripple effects' as defined by Peirce, 1986: 224-229). Not all of these effects can be

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[10] This phenomenon has been analyzed in the concept of external economies by development theorists in the context of investment decisions (for example, see Scitovsky, 1954, and Chenery, 1959. For an excellent study of this problem in the mechanical engineering industries, see Vietorisz, 1968 and 1972, and Westphal and Rhee, 1975.) Here, we use the term in a broader sense including all economic activities (design, production, etc.) in addition to investment activities. Note that interdependencies do not necessarily lead to unpaid benefits.

foreseen nor can all of their benefits be appropriated by the designer/-developer ('incentive' and 'uncertainty' problems). In other words, the development potentials of new technologies and the solutions to technical problems may not be fully understood (even by specialists) since the information and technologies are dispersed among firms that are involved with only a small fraction of activities concerning metalworking processes. This phenomenon is a direct result of the dispersed character of information, and uncertainties arise accordingly. Explicit market transactions and signals (changes in relative prices, etc.) may not be enough to resolve this problem and various types of non-market relations (chiefly, informal information transfers concerning technological capabilities and the needs of closely related firms) may be important for firms to be innovative and profitable.

2) *Scale interdependencies* arise when there are economies of scale in any activity for the production of related products. When these activities are carried out in different firms, their explicit, non-market coordination may become necessary even for their coming into existence. Since many researchers stress the importance of economies of scale in various activities in the production of machine tools and other related equipment[11], this factor

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[11] Pratten (1971: 66-68), UNIDO (1984: 92), and Jacobsson (1986: 98) are among those researchers who stress the importance of economies of scale in machine tool production. Economies of scale may arise because of indivisibilities (e.g., design activity), and learning by doing in manufacturing. Arrow (1962) shows the occurrence of economies of scale as a result of learning by doing in a general, abstract model of economic development. Hirsch (1952 and 1956) measured empirically cost reductions in machine tool manufacturing by learning and argues that they are highly significant.

alone may create significant influence in favor of non-market coordination.

This type of interdependence under economies of scale occurs if i) some resources can produce various parts that are used in different products (e.g., manufacturing of shafts for an electric motor and spindles for a drilling machine by the same lathe), ii) different products use the same parts (e.g., thousands of products use high-tensile screws and bolts), and iii) different parts are used in the same product (e.g., both NC units and ballscrews are used in an NC machine tool). Note that the abundance of these relationships is an important characteristic of the metalworking industries.

A simple example may be helpful to show this type of interdependence. Assume that there are two firms: Firm A and Firm B are conventional machine tool and materials handling equipment producers, respectively. Their design and development (D&D) costs, and production costs for new CNC machine tools and material handling robots are as follows.

	Firm A	Firm B
D&D cost for CNC machine tools	$225,000	$500,000
D&D cost for robots	400,000	200,000
Average prod. cost for NC MTs	10,000	10,000
Average prod. cost for robots	1,000	1,000

Demand function for NC MTs $Q_m = 400 - .025\ P_m$

Demand function for robots $Q_r = 100 - .025\ P_r$

Demand function for machining cells $Q_c = 800 - .050\ P_c$

Note that since Firm A has accumulated knowledge in the design of machine tools, its design and development cost for the new NC machine tool is lower than that of Firm B. In the same way, Firm B has an advantage in the design of new material handling robot. The source of economies of scale is the indivisibility of design activity. There are constant returns to scale in production, and both firms have the same unit production cost. Also assume that with minor design modifications, the new NC machine tool and robot can be connected to build a machining cell which has a separate demand function. Under these conditions and without any explicit coordination, Firm A produces only 75 units of NC machine tools with zero profit (average cost = price = $13,000), and Firm B produces neither NC machine tools nor robots at all. But if they learn their cost structures via informal contacts and coordinate their design and production, Firm A produces 200 NC machine tools of which 125 units go to build machining cells, and Firm B produces 163 robots (again, 125 units for machining cells), and their total profits become $170,000. Thus, market transactions alone may not lead to the optimum production level without explicit coordination of design and manufacturing activities in both firms.[12]

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[12] Depending on the cost structures, different outcomes could be obtained. For example, if Firm B's D&D cost for robots was $100,000, first Firm A would produce 75 units of NC machine tools with a price tag of $13,000. Then Firm B, buying NC machine tools from Firm A would produce 38 units of stand-alone robots and 50 units of machining cells. Being faced with a new demand structure, Firm A would increase its production and reduce the price of NC machine tools due to scale economies. For example, when Firm A set the price for $2,760 (137 total units of output) where it obtains maximum profits, Firm B would produce 56 units of machining centers and 38 units of robots. At this 'equilibrium' point, profits of Firm A and Firm B would be $153,120 and $18,960, respectively. But at the global optimum point that could be

This discussion on the technological and scale interdependencies suggests that the unit of analysis of technological change and the coordination of economic activities can not be confined to a firm in isolation since this type of approach pays little attention to technological complementarities, interfirm relations and non-market mediated information flows which may be crucial for the understanding of changes in the machine tool technology. For this reason, the unit of analysis in this framework should be at the meso-level where the concept of 'development block' plays the central role.[13]

By development block we mean a set of closely interrelated and interdependent activities and techniques for a given economic domain. In this context, the development block that is considered is 'factory automation' which includes all activities concerning the development, manufacturing and use of all kinds of equipment employed in the metalworking processes and related auxiliary activities at the shop-floor level (namely, machine tools, materials handling equipment, and control systems). The analysis of the factory automation development block emphasizes the underlying technological structure with its products, processes and their interconnections. Since this study is focused on a small part of the factory automation block

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obtained by non-market coordination mechanisms, total profits would be higher ($268,740) with the outputs of 75 NC machine tools, 125 machining centers, and 38 robots. In this case, the cost of relying upon the market mechanism could be the delay in the production of robots and machining cells (which may, indeed, be very important), and lower total outputs and profits.

[13] This concept was first developed by Dahmen, 1989.

(supply of machine tools and related technologies), a detailed analysis of the factory automation block is beyond the scope of this study.

Interdependencies between activities that form the factory automation block lead to a position where market transactions and signals may not be sufficient for an effective and efficient coordination. The information should be transferred among economic agents without explicit market transactions. This is the basic reason why various types of interorganizational linkages and informal methods of information exchange are formulated in real economies.

A relatively more formalized type of interorganizational relationship that can deal with the problem of interdependencies is intermediary organizations referred to as 'networks' (see Imai, 1989). Network is a type of coordination mechanism which is halfway between 'markets' and 'organizations'.

> The reason why these intermediary organizations were formed was basically to cope with failures in both the market and in the organizations. With regard to technology [the subject currently being discussed], market failure results from a lack of sharing and mutual accumulation of technical information between firms engaged in trading with each other. On the other hand, organizations tend to manifest the defects of becoming rigid in structure and bureaucratic in nature. The ability to maintain flexibility in response to the market is an advantage of the intermediary organization. (Imai, 1989: 138)

Of course, there are less formal methods of information exchange. The practice of informal ‘technology sharing’ and ‘information swapping’ is a prevalent mode of information exchange that deals with this problem. (von Hippel’s study (1988) is rich in the description of those types of information exchange in various industries.)

In brief, interdependencies between activities that are complementary, use the same resources, or are connected with input/output relations may occur when there are economies of scale in any one of these activities (including design, production, marketing, etc.). Thus, the unidentified and uncertain ‘ripple effects’ and interdependencies arising due to economies of scale may lead to non-market coordination of activities in metalworking processes by various types of intermediary organizations (‘network relations’) or informal ‘technology sharing’. New technological developments in the field of computerized numerical control that emphasize the integration of manufacturing systems have enhanced those types of interdependencies. The recent increase in mergers/acquisitions and technical/marketing cooperation agreements between firms operating in this field can be explained by these factors to a large extent. The need for non-market information flows is also recognized by many observers. For example, a study by the National Academy of Engineering (1983: 53-54) concludes that ‘there is a continuing need for closer communication between machine tool builders, their vendors and customers. More information-sharing and cooperative ventures (including subcontracting) within the industry could be of great benefit.’

As can be seen in this analysis, the key to coping with the problem of interdependencies is good information connections. Since it may be expected that proximity (both geographical/cultural/legal and manufacturing philosophy) is important for informal information transfers, a domestic machine tool industry that supplies technological capabilities to other interrelated industries may be important for the coordination of various economic activities.

2.5 Conclusions

In this chapter, the characteristics of the design and development process in the machine tool industry, the specifics of machine tool user/producer relationships, and possible sources of benefits created by a domestic machine tool industry were investigated. From this analysis, two quite different hypotheses can be derived.

In the analysis of the effects of a domestic machine tool industry, it is stated that the existence of this industry can be beneficial to the development of domestic engineering industries as a result of difficulties in (informal) information transfer (including labor mobility, professional contacts in everyday life, implicit contracts, etc.) across the national boundaries. Thus, the arguments in favor of a domestic machine tool industry can be summarized as in the following testable hypothesis: The development of a domestic machine tool industry stimulates the development of domestic engineering industries by creating some external economies, satisfying closer producer/ user interactions, supplying better custom-designed products, reducing users' costs, facilitating better coordination of economic activities, etc. Recall that the magnitude of these effects is an empirical problem since the relative importance of the difficulties in information transfers across the national boundaries cannot be determined a priori in any theoretical framework.

Two implications of this hypothesis are worth mentioning. First, it is a strong hypothesis in the sense that it should be valid in any country at any time period to be true. Second, this hypothesis implicitly signifies a stronger causality running from the development of the engineering industries to the development of the machine tool industry since all those effects (externality, closer user/producer relations, etc.) may be even more powerful in the reverse direction, i.e., from the engineering to the machine tool industry, given the relative sizes of industries, and the intensity of technology flows in both directions. It is thus not surprising that a cross-sectional study by UNIDO found that *per capita* apparent consumption of machine tools and industrial machinery are highly correlated with some general development variables such as *per capita* GNP, capital formation, vehicles in use, etc. (UNIDO, 1974: 52-56) But simple correlations between these variables, of course, cannot show any direction of causality. The causality relations between the development of domestic machine tool industry and the engineering industries in both directions will be investigated in Chapter 6.

The second hypothesis that can be derived from our analysis is related to the industry responses to 'external' shocks. Nelson and Winter (1982: 165-169) and Nelson (1987: 24-27) argue in a special model that an industry's response to a factor price shock can be decomposed into three terms each corresponding to the operation of analytically distinguishable mechanisms: i) firms' response to changes in factor price along their decision rules (routines) at the time of shock, ii) changes in decision rules, and iii) the selection process that forces some firms to contract or expand. The tacitness of technical expertise and the dispersion of technological information among firms lead to the fact that the technological position of firms cannot be brought about 'rapidly', i.e., routines of design and development activities change slowly. Moreover, well-established connections between machine tool producers and users (such as one formed in the U.S. for a long time) may resist new connections. Thus, the second hypothesis on the industry response to 'external' shocks and its effects on user industries can be formed in the following way: the inertia in the technological position of domestic machine tool producers and in their relations with users may cause a delay in the adoption of new technologies and manufacturing systems in the course of *rapid* technological changes triggered by foreign producers. In the case of the U.S., this hypothesis suggests that the U.S. engineering industries may be negatively affected by the development of new flexible metalworking technologies by foreign machine tool firms (especially by Japanese firms who follow overall cost leadership strategy) since they may tend to be supplied by the domestic (U.S.) machine tool producers for some time even though their products may be inferior to those of the foreign producers. Of course, this effect may be overcome, and, indeed, is being overcome by the adoption of new technologies through new user/(foreign) producer relationships.

Note that there are four distinct propositions that compose this hypothesis. Two of them (flexible manufacturing technologies as the focus of recent changes in the machine tool technology, and the lack of competitiveness of U.S. producers in these fields) will be examined in Chapter 4, whereas the other two propositions (the inertia in the relationships between machine tool producers and users, and the temporary negative effects of declining U.S. machine tool industry on user industries) will be tested in Chapter 5.

CHAPTER 3

MANUFACTURING SYSTEMS IN THE ENGINEERING INDUSTRIES

3.1. Introduction

Metalworking technologies have been radically changed after the mid-70s by the introduction of microprocessor based NC technologies. The discussion on the effects of new metalworking technologies is generally carried out on the basis of changes in 'manufacturing systems'.[1] Thus, the focus of this chapter is the recent changes in machine tool technologies and the determination of manufacturing systems on the basis of machine tool stock data. The chapter is organized as follows. General, long-term trends in machine tool technology are summarized in Section 3.2. Section 3.3 is devoted to determining the

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[1] The essential part of the manufacturing processes employed in the engineering industries is based on metalworking processes. Hence, throughout this chapter, 'manufacturing systems' and 'metalworking systems' are used in the same meaning.

correspondence between machine tool types and manufacturing systems, and the distribution of manufacturing systems across the U.S. engineering industries. The results of this section are used to analyze recent changes in manufacturing systems and the reactions of U.S. machine tool producers by using data based on machine tool types (Chapter 4), and the effects of manufacturing systems employed by the engineering industries on the international competitiveness (Chapter 5).

3.2. Long-term Trends in Machine Tool Technology

Periodization of the long-term trends in machine tool technology is possible on the basis of the occurrence of major changes. Three major periods, with some overlap, can be recognized in the historical development of machine tool technology, where each period is represented by the main focus of development. The first period (before 1900) was characterized by mechanical devices replacing manual work (Sator, 1969:401). That is, the main trend in this period was the substitution of inanimate sources of power for human power (mechanization of the transformation process). In the second period (1900-1970), the combined (mechanical, hydraulic and electrical) devices and controls connected with weak-current electronics were developed to mechanize the transfer and some control operations (transfer lines and automatic stand-alone machines). At the beginning of this period, the major share of the machining cycle was spent for actual cutting operations.

Consequently, the development of cutting tool materials aimed of increasing cutting speeds took place after 1900. The third period (after 1970) is characterized by the development of semiconductor-based numerical control (NC) techniques. Note that these changes roughly correspond to the mechanization of transformation (actual metalworking operation), transfer (of workpieces and loading operations), and control functions in the manufacturing processes.[2]

The three basic dimensions of metalworking, i.e., transformation, transfer and machine control functions, can be represented in a three-dimensional matrix. Figure 3.1 depicts the variables of these dimensions (adopted from Bell by Blackburn et al., 1985: 51-54).[3]

Currently, any machine tool is non-human powered by definition. Thus, the relevant portion of this matrix becomes two-dimensional for metal-cutting operations. (But in some other closely related processes such as assembly

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[2] The description of the history of machine tool technology is very brief since it is not our main concern. For details, see Sator (1969), Carlsson (1984), and Woodbury's various monographs.

[3] The variables in the control-dimension of this matrix are described as follows. Single-operation memory: any machine tool with powered tool/work-piece movement that perform single-operation actuated by worker. Multi-operation memory: installing tools for many operations in a turret type equipment (sequencing is done by manually). Multi-operation memory plus sequencing: same as before but sequencing is done automatically. Full but inflexible memory: all information for a full cycle (operations, sequencing, etc.) are installed by means of mechanical devices. Semi-automated input with limited memory: the plug-board control and, possibly, camless-auto types of systems. Semi-automated input with unlimited memory: NC systems which are very similar to those in the above category. Fully automated input: Direct computer control systems. Fully automated input plus multi-variable feedback: Computer controlled systems with feedback control of a large number of operating parameters ('adaptive control').

work, the transformation is usually carried out manually, by hand tools or powered hand tools.) Moreover some categories might not be relevant for metal-cutting processes (especially the top-left corner) since they are not economically feasible.

The development of machine tool technology in the early 1900s was from the bottom-left corner [1.1] to bottom-middle [4.1] and top-middle [4.4], i.e., to mass production. Recent developments have occurred in the lower-right part of the matrix (development of NC and CNC machine tools) and started to go up (various forms of flexible automation technologies).

A sample of machine tools for relevant possibilities of this matrix are as follows.

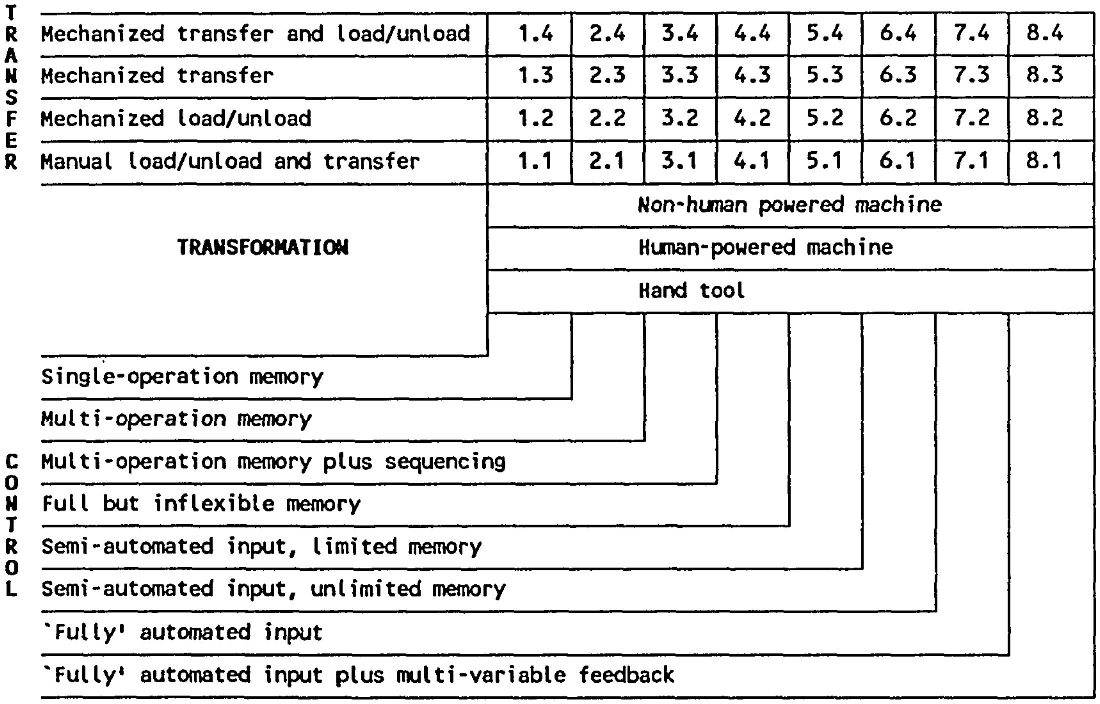
1.1 Conventional machine tools
2.1 Capstan and turret type machine tools
3.1 Tracing and copying machines, manually loaded 'automatics'
4.1 Manually loaded special purpose machines
3.2 Mechanically loaded 'automatics'
4.2 Mechanically loaded special purpose tools
3.3 'Automatics' with transfer systems but manual loading-unloading (an unlikely combination)
3.4 'Automatic' link lines transferring similar parts between 'automatic' machine tools
4.4 Transfer lines
5.1 Early NC machine tools
6.1 Early NC machine tools and PC controlled machine tools
7.1 CNC machine tools
7.2 CNC machine tool with robot (FMC)
7.3 CNC machine tools with transfer system or AGVs
7.4 FMSs
8.1 Adaptive control CNC machine tools (not fully developed)

These categories are also closely related to scale of production roughly according to the following groupings.

Production volume	Categories
Small-medium batches	1.1 2.1 3.1 5.1 6.1 7.1 7.2
Large batches	3.1 3.2 7.3 7.4
Long runs, continuous mass production	4.1 4.2 3.4 4.4
Long runs and large batches, but uncommon	3.3 4.3

Lastly, it should be stated that each category in this matrix can be differentiated by machining attributes such as performance, accuracy, precision, workpiece size, etc.

Figure 3.1 Mechanization levels of metalcutting processes



Recent changes in machine tool technology as depicted in Figure 3.1 can be explained in terms of the focus of interest on various parts of the total manufacturing time, i.e., in terms of focus of development on those bottleneck activities that constitute the major part of the total manufacturing time or become obstacles to the realization of development potentials of other activities. In the last couple of decades, the actual cutting time has been reduced to only a fraction of total available machine time in a wide range of metalworking operations based on small and medium batch manufacturing. It has brought the non-cutting times, and, especially, the setting-up times into prominence. Thus, major reductions could only be obtained by reducing time spent for control functions (such as feeding cutting tool, changing speeds and feed during operations, etc.) and auxiliary operations (such as loading, tool change and setting-up).

By reducing the time spent for those control functions by NC, the relative proportion of machine tool cutting time has been increased, in some cases, from a 10-30% range for conventional machine tools to a 60-80% range (Krainov, 1975: 45). Loading and tool change operations are also being automated by NC equipment for small- and medium-batch production. This development further increases the share of time spent during the 'productive' use.

The dual nature of set-up operation is another important element in the development of computer control. Reductions in the set-up operations directly increase machine productivity. But, more important, reductions in set-up time also reduce the minimum optimal batch size. It may decrease manufacturing costs, since work-in-process inventories may be reduced to a large extent, and the flexibility and responsiveness of production can be increased (see Dietz, 1979, and Eversheim and Herrmann, 1982).

The improvements in the control operations as a result of this 'mechanization' by NC are considered to have the highest impact on small and medium batch operations, since there have been economical methods of mechanized control for high-volume production for a long time. By new technologies, an effective combination of flexibility and automation has been achieved for the first time for small and medium batch production in the metalworking processes.

There are three major effects of new controls developed after the late-1970s. These effects can be summarized as follows:

i) The developments have weakened the link between mechanization and scale. The 'flexible' form of automation permits increased variability in products and processes to be accommodated at higher levels of automation.

ii) Different productive sub-units ('islands of automation') are being integrated with each other and with materials handling equipment, stock control, and production planning (integration of production).

iii) These developments also create some changes in the organizational structures that tend to favor the adoption of work roles, rather than individual repetitive tasks organized on a hierarchical basis (Blackburn et al. 1985: 104-105). Although organizational changes are important for the realization of the benefits of these technologies (Martin, 1985, and Burnes, 1988), only the former two processes (increasing flexibility and integration) will be considered in the following sections.

While this description of the long-term trends in machine tool technology are commonly accepted, and most observers agree that recent technologies have considerably changed the manufacturing processes for small and medium production volumes in the engineering industries, there are profound differences in the evaluation of the effects and the extent of these changes, particularly on the relationships between mass production and new (flexible) technologies. This subject will be elaborated in the subsequent sections.

3.3. Metalworking Systems in the U.S. Engineering Industries

The characteristics of the available manufacturing technologies (e.g., batch/-mass production, flexibility of production, etc.) are supposed to be among the 'basic conditions' in Industrial Economics. Almost any behavior of firms and industries and, consequently, their performance are conditioned and constrained by this factor. There are many theories and hypotheses proposed to explain the relationships between the characteristics of the manufacturing systems (with a special emphasis on computerized, flexible technologies) employed by firms and industries, and other economic phenomena such as the size distribution of firms, international competitiveness, etc. But, unfortunately, there is not a complete data set for the distribution of manufacturing *systems* suitable for an econometric examination of these relationships. Therefore, researchers tend to use some proxy variables to represent various manufacturing systems and their characteristics. For example, Toh (1982) uses the level of expenditures on new machinery and equipment per worker as a proxy variable for the level of mechanization. He tests the hypotheses that the extent of intra-industry trade is likely to be greater, the longer is the production run and that production runs are longer when production processes are adaptable to mechanization and low human-capital utilization.

The effects of recent changes toward increasing integration of manufacturing machinery and equipment have intensified the need for the study of *systems* instead of looking for the changes in the share of specific machine tool types. As stated in a study by the Department of Labor (1982: 21), '[t]he innovation of [NC] may be more fully appreciated by characterizing NC as a manufacturing system, and not merely as a means to control a machine'. Thus, in this section, the manufacturing systems in the U.S. engineering industries and the correlations between manufacturing systems and machine tool types are described on the basis of machine tool stock data, as interpreted statistically through factor analysis.[4]

3.3.1. Method

Several classifications of metalworking technologies have been proposed to date, mostly on the basis of volume/variety characteristics. Although these classifications are two-dimensional, they lead to a one-dimensional picture, since a trade-off between volume and variety (productivity and flexibility) is assumed.[5] Figure 3.2 depicts a commonly used classification (Hegland, 1981). A different approach, the so-called product-process matrix of Hayes and Wheelwright (1979a and 1979b) has reached basically the same results.

In this section, major manufacturing systems, as depicted in Figure 3.2, will be determined by factor analysis from the machine tool stock data since there is a close relation between some types of machine tools and manufacturing systems. There are two basic relationships between machine tool types and manufacturing systems that can be used for classification (see also UN ECLA, 1969).

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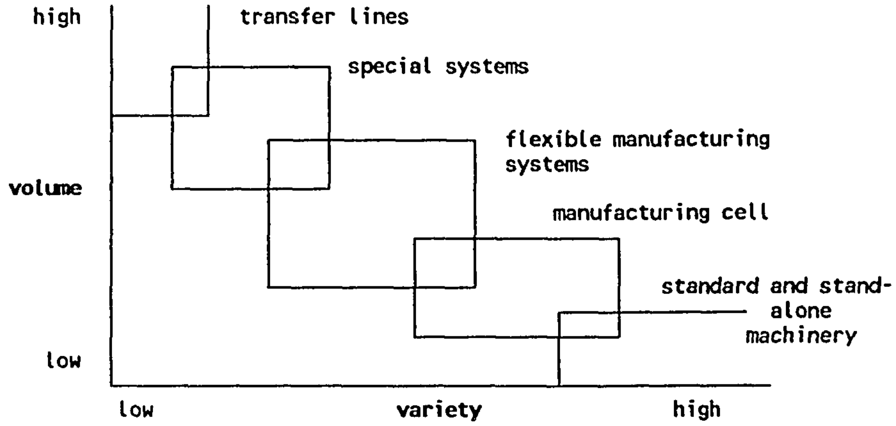
[4] The engineering industries are characterized by similar manufacturing technologies based mainly on metalworking processes. Therefore, it may be possible to classify the manufacturing systems in these industries on the basis of the distribution of different types of machine tools.

[5] The trade-off between volume and variety is assumed on the basis of the alleged efficiency of dedicated (inflexible) machinery for high volume production.

Figure 3.2 Classification of manufacturing systems



Source: Hegland, 1981.

i) Some types of manufacturing processes performed by specific machine tools are generally suitable for only the low (or high) volume end of the production spectrum because of their basic technological characteristics. For example, planing and electro-discharge machining processes are not used for mass production. Similarly, broaching processes are never economical for low-volume production.

ii) Some manufacturing processes can be used at all levels of production, but some types of machine tools that perform these processes are specially designed for producing small batches of different workpieces while other types (e.g., multi-spindle machines, automatics, etc.) are used primarily in manufacturing of large batches of workpieces.

Consequently, a close correlation between some types of automatic and special-purpose machine tools and manufacturing systems may be expected.[6]

A factor analysis method of determining the manufacturing systems in the U.S. engineering industries can be summarized as follows. It can be assumed that manufacturing systems are characterized by a definite composition of machine tools. That is, the distribution of machine tools across industries is determined by the distribution of different manufacturing systems across industries. This relation can be summarized as in Equation 3.1.

[3.1] $X_{iv} = w_{v1}F_{i1} + w_{v2}F_{i2} + \ldots + w_{vf}F_{if} + w_{vi}U_{iv}$, where X_{iv} is the share of the v^{th} machine tool in the total number of machine tools in the i^{th} industry (at SIC 3-digit level), F_{ki} is the 'share' of the k^{th} manufacturing system in the i^{th} industry, w_{vk} is the loading on the k^{th} manufacturing system for the v^{th} machine tool, and U_{iv} is the unique, industry-specific share of the v^{th} machine tool that is not explained by the common manufacturing systems. The concept of 'loading' can be loosely interpreted here as 'the number of the v^{th} machine tool in a manufacturing system of the k^{th} type'. This relation can be expressed in matrix form as follows.

[3.2] $X = FW' + UB'$, where X is an n*v (n by v) matrix of machine tools, F is an n•f matrix of manufacturing systems, W is a v•f matrix of loadings, U is an n•v matrix of industry-specific unique 'systems', and B is a

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[6] Figures 2.2 and 3.1 show some of the expected correspondence between specific machine tool types and manufacturing systems.

v•v diagonal matrix of unique factor loadings. The subscript n is for the number of industries, v for the number of different machine tools used in this analysis, f for the number of manufacturing systems where $f<v<n$. (In factor analysis, standardized forms of the X and F matrices are generally used so that each column of the X and F matrices have zero mean and unit variance.)

Our purpose is to find the F and W matrices, given the X matrix. This formulation of the problem leads us to solve the F and W matrices by using factor analytic procedures. In Equation 3.2, only the X matrix is known. Therefore the weights and factors cannot be solved *uniquely* (there is an infinite number of weight/factor sets by which the variables can be calculated) without further assumptions. For example, in principal factor methods each factor is extracted from the correlation matrix of the original variables, S, ($S=X_s'X_s/n$, where X_s is the standardized form of the X matrix) so that it accounts for the maximum possible amount of the variance of the correlation matrix being factored, under the condition that it is uncorrelated with the previously extracted factors.

Equation 3.2 can be written in the standardized form as follows.

[3.3] $X_s = F_sP' + U_sD'$, where X_s, F_s, and U_s are the standardized forms of X, F, and U matrices, P and D are corresponding weight matrices. The P matrix is called the factor pattern matrix. Under the usual assumptions of factor analysis (zero correlation between unique factors, and between common factors and unique factors), Equation 3.3 can be transferred into relationships among correlation matrices as follows.

[3.4] $R_V = PR_FP' + Z$, where R_V is the v*v correlation matrix of the original variables, R_F the f*f correlation matrix of factors, and Z the v*v diagonal matrix of the squared unique factor loadings. If common factors are assumed to be uncorrelated with each other as assumed in the principal factor methods, R_F is equal to the identity matrix. One of the main purposes of the factor analysis is to determine the factor pattern matrix, P, which also represents the correlations between original variables and common factors under the above mentioned assumptions. In our case, the factor pattern matrix gives us the correlation coefficients of machine tools by manufacturing systems. The procedure that determines the P matrix is called 'factor extraction'. (For a detailed explanation of these methods and other concepts of factor analysis, see Gorsuch, 1983. The statistical package to be used in this study is SPSS/PC. For the procedures available in this package, see Norusis, 1986.)

The data used in this analysis were obtained from the American Machinist Inventory of Metalworking Equipment (AM, 1983a) for 43 3-digit industries in SIC 34-38 categories (for a summary of this inventory and its methodology, see AM, 1983b. For industry definitions, see Table A.7 at the end of this Chapter). Metal-cutting machine tools are given in 78 types in the AM Inventory. Since it is not statistically possible to use the machine tool data at this level (the number of variables should be less than the number of observations), they have been aggregated into a smaller number of groups by considering their technological characteristics. Some of the aggregated groups have been selected to be used in this study depending on their size, interpretability and Kaiser-Meyer-Olkin measure of sampling adequacy[7] for factoring (for these groups, see Table A.1). Factor analysis been carried out for 22 metal-cutting machine tool groups. (In this analysis, only metal-cutting machine tools have been used since this group is one of the technologically most dynamic groups among all metal-working machines and its share in total number of machine tools is higher than 75%.)[8]

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[7] In factor analysis, it is explicitly assumed that there are some 'latent' factors which are, to a large extent, responsible for covariations of the original, observable variables. Since factors account for the overlapping variations in the data, it is necessary to have 'high' correlations between at least some of the original variables. A commonly used index to determine the adequacy of observed correlations between original variables is the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy. This index compares the magnitudes of the observed correlation coefficients to the magnitudes of the partial correlation coefficients. As a rule-of-thumb, it is suggested in the literature not to use factor analysis if KMO is less than .5.

KMO index is computed as

$KMO = \Sigma\Sigma_{i \neq j} r_{ij}^2 / (\Sigma\Sigma_{i \neq j} r_{ij}^2 + \Sigma\Sigma_{i \neq j} a_{ij}^2)$ where r_{ij} is the simple correlation coefficient and a_{ij} is the partial correlation coefficient between variables i and j. KMO can be computed for each variable separately to indicate the adequacy of that variable for factoring. For the ith variable, KMO is defined as

$KMO_i = \Sigma_{j \neq i} r_{ij}^2 / (\Sigma_{j \neq i} r_{ij}^2 + \Sigma_{j \neq i} a_{ij}^2)$ (Norusis, 1988: B-45).

[8] Metal-forming machine tools are not generally used in 'systems'. As a result of this phenomenon, the correlations between various types of metal-forming machine tools are low. Factor analysis is not suitable if correlations between variables are not high enough, as explained in the preceding footnote. Therefore, metal-forming machine tools were not included in this analysis.

3.3.2. Results

The correlation matrix of machine tools has been tested for adequacy for factoring. The Bartlett test of sphericity is very high (significance level=.000001) which means that the correlation matrix is significantly different from the identity matrix. On the other hand, the overall Kaiser-Meyer-Olkin measure of sampling adequacy is relatively low (.62), although it is acceptable.

Factors have been extracted by using the principal components (PC) method. This method is selected mainly because of its low computational time. Since the number of variables is relatively high for this analysis, our results are robust for the factor extraction method. The stability of factors for the factor extraction method has been checked by comparing (rotated) factors for PC, principal axes (by two iterations as suggested in the literature), and maximum likelihood methods and it was found that all procedures lead to almost identical interpretations. (As an example, the results of the principal axes extraction is shown in Table A.4.)

Factors are also robust with respect to the rotation method. Quartimax and oblimin procedures give almost the same factor structure (and pattern) matrix as the varimax rotation. Moreover, the highest correlation between factors obtained by the oblimin rotation is only .16, which is not statistically significant at the 5% level. This result can show the fact that the "latent" factors are indeed orthogonal. Therefore the results of the orthogonal (varimax) rotation have been used in this paper. (For the factor structure matrix of the oblimin rotation and the factor correlation matrix, see Tables A.5 and A.6. Note that our interpretations would not be any different if those results were used.)

The number of factors to be extracted is determined by the root-greater-than-1 criterion, the scree test, the variance explained by factors, and the interpretability and replicability of factors. Although the first criterion suggests extracting seven factors, it seems to overestimate the number of underlying factors. The scree test may lead to extracting four factors (see Figure A.1.). The total variance explained by the first four factors is 62.6% and the percentage of variance explained by the fourth factor is 10.2%. To see the replicability and interpretability of factors, five factors were also extracted and their rotated factor pattern matrix examined. It was found that the additional factor does not change the interpretation of the originally extracted factors. It seems that the factors obtained by the four-factor case are well stabilized and are interpreted accordingly.

The relative distribution of manufacturing systems across the engineering industries are required to determine their relevance. For example, based on our a priori engineering information, we may expect that the factor that represents mass production system should have higher values in the motor vehicles, refrigeration and service machinery, engines and turbines industries, etc. Moreover, these data can be used in the regression analysis in

Chapter 5 to measure the effects of various manufacturing systems on the international competitiveness of the engineering industries. For this purpose 'factor scores' have been found for the four-factor case by the regression method (Table A.3). (Indeed, in the PC method, all three methods available in the SPSS/PC$^+$ package --the regression, Anderson and Rubin, and Bartlett's methods-- give identical results.) In Table A.3, a higher value of a factor score for an industry means that the manufacturing system represented by that factor is more intensively used in this industry relative to other industries.

The rotated factor pattern/structure matrix for the four-factor case is shown in Table 3.1. The factor interpretations of this matrix are as follows.

Factor 1 (F1): This factor is significantly positively correlated with broaching, honing, rotational grinding, mass-milling, boring, NC-boring, station-type, and gear-cutting machines, and negatively correlated with grinding (bench, floor, and snag grinders, etc.), batch-drilling and small-lathes. By considering the facts that broaching machines are an example of dedicated (high-volume) stand-alone machine tools because of high costs of broach making (the tool to be used for chip removal), the station-type machines are among the most important types of mass production machine tools, and that rotational grinding machines include centerless-grinding machines that are used for the high-volume grinding of rotational parts, this factor represents the high-volume end of the production spectrum. Note also that NC units in the boring machines are mainly used to increase quality and/or productivity rather than to increase flexibility since this operation needs relatively simple point-to-point motions. The coexistence of gear-cutting and rotational-grinding machines with mass-milling and boring machines as well as station-type machines may imply that this factor represents the co-production of rotational and prismatic parts used in such products as engines, gear-boxes, etc.

The highest F1 scores are found in the miscellaneous transportation equipment (including motorcycles and bicycles) industry, motor vehicle parts and accessories, engines and turbines, and guided missiles and space vehicle industries, and the lowest scores in the plumbing and heating equipment, fabricated structural metal products, and surgical, medical, and dental instruments industries (see Table A.3). In other words, the manufacturing system represented by this factor (which is interpreted as 'transfer lines' below) is used most intensively in the former industries, and least intensively in the later industries.

Factor 2 (F2): This factor is significantly positively correlated with NC-milling and batch-milling machines, NC machining centers and small-lathes, and negatively correlated with radial-drilling, grinding (bench, floor, and snag grinders, etc.), and broaching machines. NC milling, NC machining centers, and batch-milling machines are generally used for low and middle volume production of prismatic parts and small lathes are used for low volumes of small rotational parts.

Table 3.1 Rotated factor pattern matrix (Extraction, principal components; rotation, varimax)

Machine tool types	Factor 1 TLINE	Factor 2 CELL	Factor 3 FMS	Factor 4 SPEC
Broaching	.80211	-.30297		
Honing	.76745			
Rotational grinding	.72503			
Mass-milling	.71188			
Boring	.69015			
NC boring	.66939		.35574	
Station type	.65470		-.33649	.33894
Gear-cutting	.62645			.30497
NC milling		.73862		
Batch-milling		.70879		-.34172
Grinding (oth.)	-.33312	-.67545		
Small-lathe	-.32561	.66772		
NC machining center		.61631	.53325	
Radial-drilling		-.59351	.52701	
NC lathe			.76255	.34114
Batch-lathe			.54517	-.32868
Batch-drilling	-.48016		-.52944	.35705
NC drilling			.49321	
Mass-drilling				.80477
Aut.chuck.lathe				.77861
Turret-lathe			.56029	.59759
Flat/NC grinding				-.50651

Note: Coefficients lower than .3 have not been reported. This level corresponds to statistically significant correlation at the 5% level. For machine tool definitions, see Table A.1.

The highest F2 scores are found in the office and computing machines, communication equipment, electronic components and accessories, and engineering and scientific equipment industries. The ship and boat building and repairing, complete motor vehicles, metal forgings, and fabricated structural metal products industries have the lowest F2 scores.

Factor 3 (F3): This factor has significant positive correlations with four of the five NC machine tools used in this analysis: NC lathes, NC drilling machines, NC machining centers, and NC boring machines. It also has high positive correlations with turret-lathes, batch-lathes and radial-drilling machines and negative correlations with station-type, and batch-drilling machines. Since this factor has high correlations with all types of NC machine tools (except only NC milling machines), this factor represents new computerized flexible manufacturing in a broad sense. From its positive correlation with turret-lathes and negative correlation with station-type, and batch-drilling machines, it may be said that this factor occupies a place in the low-to-mid volume part of the production spectrum, as shown in Figure 3.2.

The highest F3 scores are obtained for the construction and mining equipment, aircraft engines and parts, machine tools, miscellaneous (non-electrical) machinery, and special industrial machinery industries. The industries that have the lowest F3 scores are the watch and clockwork operated devices, radio and TV equipment[9], cutlery, hand tools and general hardware, and motor vehicle parts and accessories industries.

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9. Note that the importance of the metalworking operations in the radio and TV equipment industries may not be as important as in other industries. Therefore, the results for those types of industries should be evaluated with caution.

Factor 4 (F4): This factor is positively correlated with automatic chuckers, turret-lathes, and mass-drilling machines which are used for high volume production, and NC lathes, batch-drilling, station-type and gear-cutting machines, and negatively correlated with batch-lathe, batch-milling, and flat/NC grinding machines. This factor is also a neat combination of prismatic and rotational parts manufacturing and may represent mid-volume production of relatively simple/smaller parts and its manufacturing integration level seems to be lower than that of F1.

The highest F4 scores are found in the farm and garden machinery and equipment, heating equipment and plumbing fixtures, miscellaneous electrical machinery and equipment, refrigeration and service machinery, and miscellaneous fabricated metal products industries, and the lowest scores are in the other metalworking machinery and equipment, ship and boat building and repairing, coating, engraving and other services, and metal cans and shipping containers industries.

The factor pattern matrix in Table 3.1 has led to relatively clear interpretations as stated above. The results are satisfactory at this (industry) level of aggregation in terms of interpretable factors, and these factor interpretations give a roughly similar picture to that in Figure 3.2. As in this figure, these factors may be ordered according to their optimum production volume per batch as F1>F4>F3>F2. For convenience, hereafter, these factors (F1, F4, F3, and F2) will be referred as "transfer lines" (TLINE), "special systems" (SPEC), "flexible manufacturing systems" (FMS), and "manufacturing cells" (CELL), respectively, as in Figure 3.2. (Since stand-alone machinery does not constitute any manufacturing system as used in this study, it may be represented by unique factors found by factor analysis.)

The relevance of these factors in representing manufacturing systems, and some common characteristics of machine tools used in these systems can be shown from their shares in total machine tool stock by size distribution of manufacturing establishments. Although there is no one-to-one relation between the establishment size and the volume of production, it may, nevertheless, be expected that the share of mass production machinery in large establishments increases when total machine tool stock for the engineering industries is considered. Figures 3.3-3.6 depict the distribution of machine tools that are significantly positively correlated with factors by the size distribution of establishments in the U.S. engineering industries in 1983.[10] In these figures, the share of each machine tool type in total number of machine tools of the engineering industries is shown on the vertical axis, and the size groups of establishments (in terms of the number of employees per establishment) on the horizontal axis. (For machine tool legends, see Table A.1.)

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[10] Machine tool stock data is available only in terms of number of units of machine tools. Therefore, the share values in Figures 3.3-3.6 are based on units, not value of machine tools.

Figure 3.3 Distribution of machine tools used in transfer lines (TLINE) by size distribution of establishments (in percent)

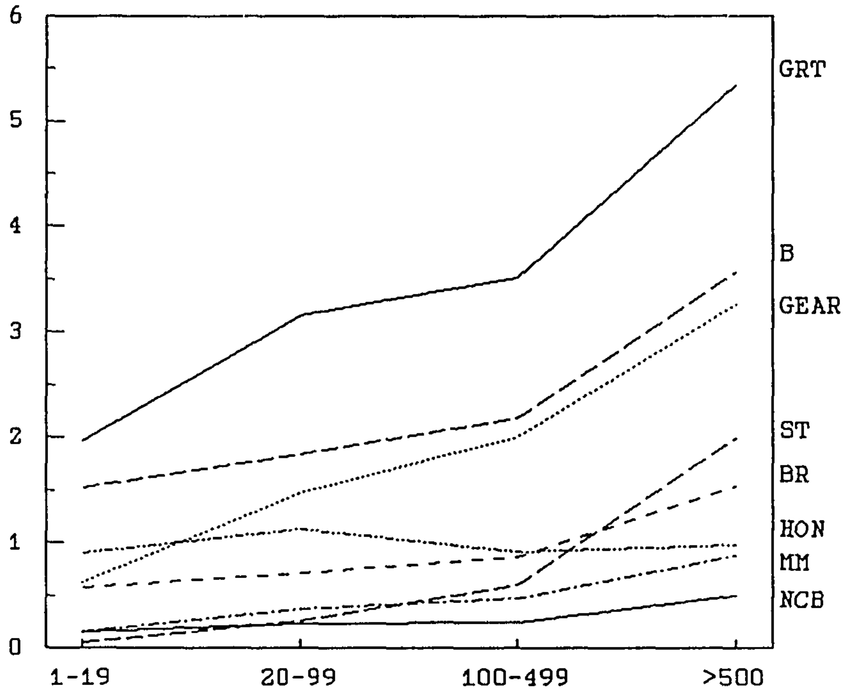


Figure 3.4 Distribution of machine tools used in special systems (SPEC) by size distribution of establishments (in percent)

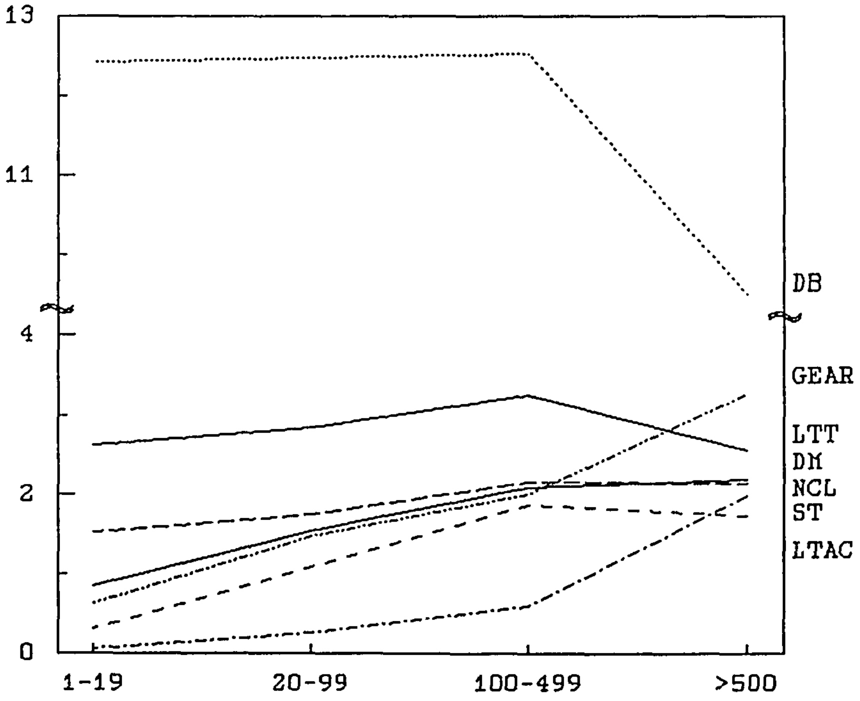


Figure 3.5 Distribution of machine tools used in flexible manufacturing systems (FMS) by size distribution of establishments (in percent)

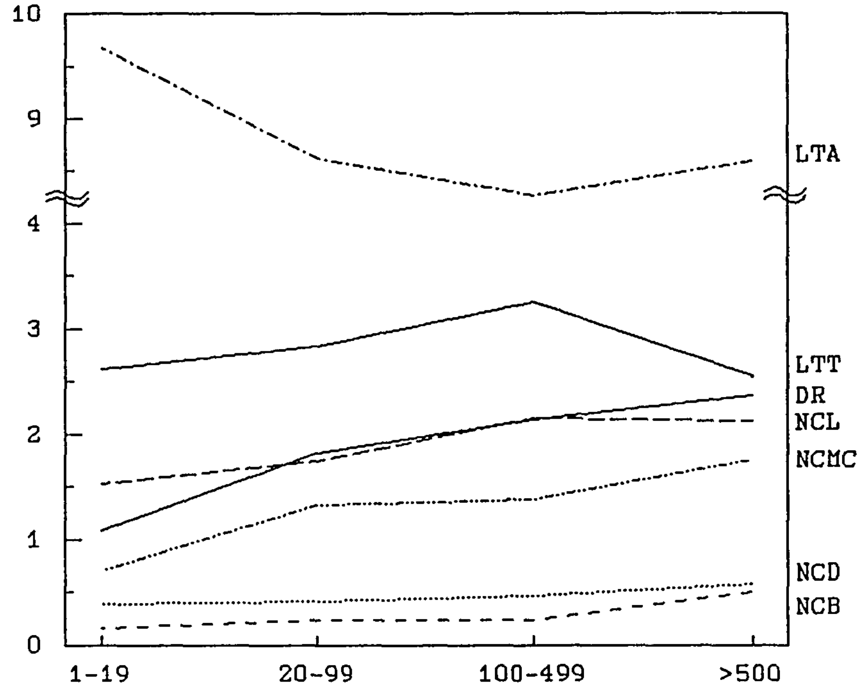
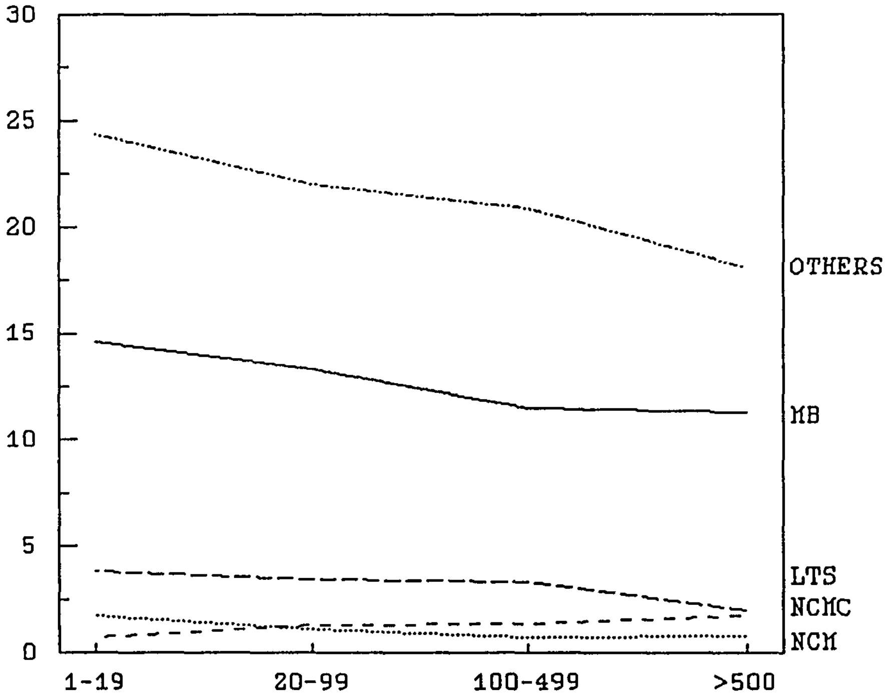


Figure 3.6 Distribution of machine tools used in manufacturing cells (CELL) by size distribution of establishments (in percent)



The distribution pattern of machine tools is relatively clear for factors TLINE and CELL that correspond to the highest and lowest production volumes, respectively. In the case of TLINE, the shares of all machine tool types that are significantly positively correlated with this factor are monotonically increasing by establishment size. (The only exception is that of honing machines whose share declines slightly from 1.13% to .91% from the size group 20-99 to 100-499.) On the other hand, the shares of those machine tools that represent CELL decrease monotonically by establishment size. The exception here is (NC) machining center which is also positively correlated with FMS.[11] As may be expected, the pattern is different for those systems that are primarily used at medium-to-high volume of production (SPEC and FMS). For SPEC factor, the shares of all machine tool types (except gear-cutting , station-type, and mass-drilling machines) increase from size groups 1-19 and 20-99 to 100-499, then decline in the size group >500. That is, medium sized establishments (100-499 employees) use these machine tools more extensively. The remaining three types of machine tools (gear-cutting, station-type and mass-drilling machines) have monotonically increasing shares. Recall that the former two machines are also correlated with TLINE factor. The pattern for the FMS factor is not as clear as that for other factors. The

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[11] The share of NC milling machines increases slightly from .71% to .77% between the size groups 100-499 and >500. The 'OTHER' category includes all those metalcutting machine tool types that are not used in factor analysis because of their low correlations with other machine tools. This category (EDMs, planers, cutting machines, etc.) are shown in this figure since they are not included in any system, i.e., they are used as 'stand-alone'.

shares of NC boring, NC drilling, radial-drilling machines, and machining centers increase monotonically by establishment size whereas the shares of NC lathes and turret-lathes increase up to the group 100-499, and then decline. On the other hand, the share of general purpose lathes declines by establishment size. These figures may reflect the willingness (and ability) of large establishments to adopt new technology and the tendency of small establishments to use general purpose non-NC machine tools in conjunction with NC machine tools to boost their flexibility.

3.4. Conclusions

In this chapter, recent changes in the machine tool technology were summarized. Major manufacturing systems, their components, and their distribution across the U.S. engineering industries were determined on the basis of the machine tool stock data of these industries by using factor analysis. The distribution of machine tools correlated with these manufacturing systems by the size distribution of establishments were analyzed to shed light on some of the characteristics of these systems. The results of this analysis are used in the subsequent chapters.

Table A.1 Metalcutting machine tool definitions

Legend	Name	Description
NCL	NC lathe	All NC lathes
LTS	small-lathe	engine and toolroom lathes up to 8-in. swing over slide
LTA	batch-lathe	All non-NC lathes exc. others
LTT	turret-lathe	Turret lathes
LTAC	automatic-chucker	Automatic chuckers
LTAB	automatic-bar	Automatic bar lathes
LTVR	verticle-lathe	Verticle lathes
NCB	NC boring	All NC boring machines
B	boring	All non-NC boring machines
NCD	NC drilling	All NC drilling machines
DB	batch-drilling	Vertical upright (hand or power feed) drilling machines
DR	radial-drilling	Radial drilling machines
DM	mass-drilling	Multi-spdl cluster drllng m/c
NCMC	NC mach. centr.	All NC machining centers
NCM	NC milling	All NC milling machines
MB	batch-milling	All non-NC milling machines exc. MM
MM	mass-milling	Automatic and manufacturing milling machines
GEAR	gear-cutting	Gear cutting and finishing m/c
GRT	rotational grinding	External and internal (plain univ. centertype, centerless, and chucking) and tool and cutter grinding machines
GFS	flat/NC grinding	Rotary table, reciprocating (hand and power, horizontal and vertical) grinding machines
GOT	grinding (other)	Bench, floor and snag grinders, disk grinders, all other grn.
HON	honing	Internal and external honing machines
LAP	lapping	All lapping machines
POL	polishing	All polishing machines
ST	station-type	Way type, rotary transfer, and in-line transfer machines
BR	broaching	All broaching machines
EDM	EDM	Electro-discharge machines (all types)
SWN	sawing	Sawing and cutting machines
OTH-NCMC		Other NC metalcutting machine tools
OTH-MC		Other non-NC metalcutting machine tools

Table A.2 Classification of metal-cutting machine tools

Legend	American Machinist (10XXX)	Production (354X.XX)	Export (674.XXXX)	Import (674.XXXX)
NCL	101-6	5.11,2,3,	.3503,5,7,9	.3504,6,8,10
		5.21,4,6	.3276,	.3476,
			.3521,3	.3505,
			.3519	.3519,21
LTS	201	5.14 }		
LET	202,3	5.22,3,5,9 }	.3510	.3512
		5.37 }		
LTT	205	5.54	In LOT	In LOT
LTAC	206,7	5.63,6,7	.3511,2	.3513,4
LTAB	208,9	5.81,8	.3515,6	.3515,6
LVTR	210	5.85,6,7,9	.3277	.3477
		5.90,8	.3525	.3522
LOT	204	5.72	.3518	.3518
	211	5.56		
LTA = LET+LVTR+LOT				
NCB	301-4 }	1.10,1,5 }	.3245,6,7	.3417,8,9
	}	1.55 }		
	}	1.72 }		
B	401-5 }	1.92 }	.3248,9	.3481,3
	}	}	.3273	.3422,3
	}	}	.3281,3	
NCD	501	2.XX	.3254	.3328
DB	601	2.97	.3257	.3336
		2.22		
DR	602	2.33	.3256	.3334
DM	603	2.52	.3255	.3329
		2.68		
DOT	604,5	2.82	.3258	.3342
		2.98		
NCMC	701-5	A.01,3,5,7,9	.3204,6,9	.3404,6,9
		A.11,3,5,7,9	.3211	.3411
NCM	801-5	6.XX	.3264	.3464
MB	901-3	6.09	.3266,7,9	.3466,7,9
	905-7	6.22,5,7,9		
		6.53,63,97		
MM	901-4	6.31,5	.3268	.3468
GEAR	1001-4	3.12,31	.3020,45	.3025,35,45
		3.71,74,99	.3529	.3527
GRT	1201-5,9	4.11,3,5,6,7,9	.3541,2	.3554,6
		4.23		
GFS	1206-8	4.33,4,7,9	.3533,8	.3539,41,43
	1101	4.XX	.3528	.3546
GOT	1210-13	4.44,6	.3546	.3559
		4.92,10		
	1209	4.52	.3531	.3528,9

Table A.2 Continued.

HON	1301-2 }	4.75,9 }	.3532 }	.3533
LAP	1303-4 }	4.83 }	}	
POT	1305-6 }	4.65,9 }	.3544 }	.3558
ST	1401-3	B.31,3,5,7	.3216,25	.3412,3
BR	1501	C.51	.3566	.3578
EDM	1201-4	C.65,7,9	.3547,9	.3562,4,7
		C.71	.3551,3	.3571
SWN	1801-5	C.53,5,7,9	.3565	.3577
		C.61		
OTH-NCMC	1901	C.XX	.3559	.3576
	2201			
OTH-MC	2301	C.41	.3557	.3574,9
	1701	C.63	.3567	
	2001	C.93		

Note: Numbers in this table refer to classification of machine tools in the AM, production, and trade statistics. First two or three digits of them were given at the beginning of the table.
Sources:
AM : AM (1983a).
Production: SIC-based codes, DoC, *Current Industrial Reports: Metalworking Machinery,* Series MQ35W(xx)-5
Exports : DoC, *U.S. Exports,* (FT446) Schedule B export numbers
Imports : DoC, *U.S. Imports,* (FT246) TSUSA import numbers

Figure A.1 Eigenvalue plots

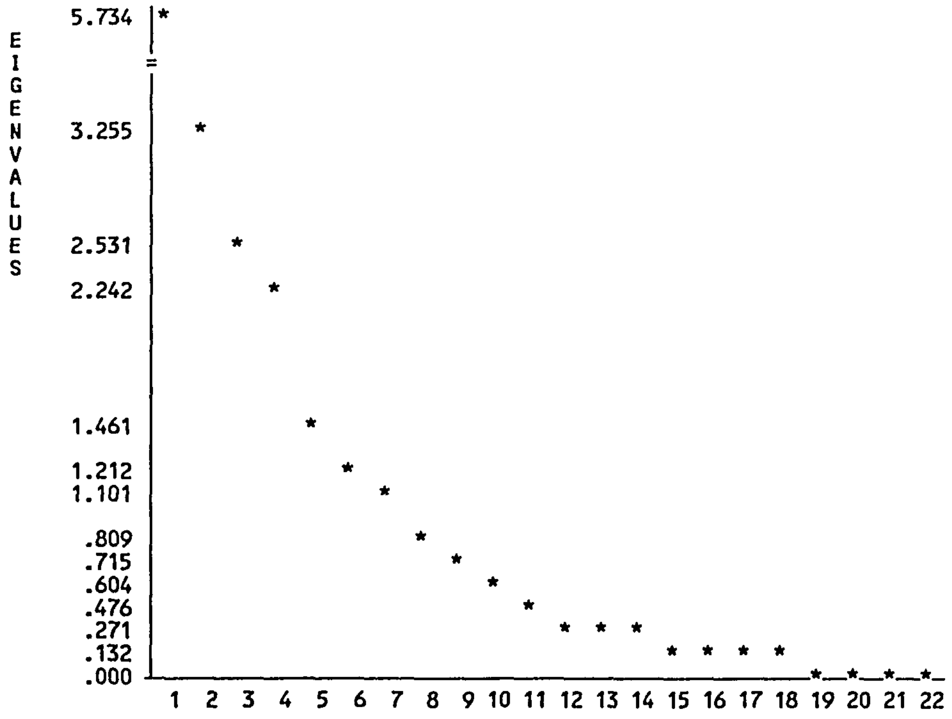


Table A.3 Factor scores

Industry	SIC	FACT1	FACT2	FACT3	FACT4
Metal cans and shipping con.	341	-0.732	-1.081	-0.116	-1.688
Cutlery, hand tools & gen.hard.	342	-0.089	-0.547	-1.546	0.049
Heating eqmt and plump. fixtures	343	-1.426	-0.841	-0.067	1.704
Fabricated str. metal products	344	-0.982	-1.284	0.157	-0.686
Screw machine products	345	0.376	-0.380	-1.111	0.256
Metal forgings	346A	-0.387	-1.299	0.407	-0.855
Metal stampings	346B	-0.436	-0.324	-1.010	-1.384
Coating, engraving and other ser.	347	0.406	0.023	0.037	-2.147
Ordnance and accessories	348	0.603	1.267	-0.718	-0.664
Misc. fabricated metal products	349	-0.598	-0.380	0.551	1.134
Engine and turbines	351	1.381	0.041	0.647	0.888
Farm and garden machn. and eqmt	352	-0.181	-0.791	-0.157	2.250
Construction, mining eqmt	353A	0.198	-0.895	3.619	0.899
Materials handling mach. and eqmt	353B	-0.702	-1.039	1.008	0.878
Machine tools	354A	0.904	0.219	1.175	-1.169
Other mtwrkng mach. and acc.	354B	0.600	0.456	0.314	-2.036
Special industrial machinery	355	-0.150	-0.204	1.139	-0.545
General inds. mach. and eqmt	356	0.837	-0.381	0.795	0.819
Office,comp. and account. mach.	357	-0.350	2.039	-0.087	0.097
Refrigeration and serv. ind. eqmt	358	-0.203	-0.575	-0.401	1.145
Misc. machinery, except elec.	359	0.473	0.812	1.146	-0.282
Elec. trans. and distr. eqmt	361	-0.869	-0.205	-0.682	-0.017
Electrical industrial apparatus	362	0.014	0.211	-0.127	0.350
Household appliances	363	-0.353	0.500	-0.615	0.143
Elec. lighting and wiring eqmt	364	-0.681	0.193	-1.324	0.703
Radio and TV eqmt	365	-0.570	0.470	-1.558	-0.308
Communications eqmt	366	-0.696	1.602	0.246	0.194
Electronic components and acc.	367	-0.718	1.373	0.009	-0.277
Misc. elec. mach. and eqmt	369	-0.062	0.303	-0.449	1.183
Complete motor vehicles	371A	0.842	-2.001	-1.106	-0.299
Motor vehicle parts and acc.	371B	2.499	-1.141	-1.360	0.693
Complete aircraft	372A	-0.542	0.240	0.407	-0.024
Aircraft engines and parts	372B	0.781	0.977	1.499	-0.551
Ship and boat building and repair.	373	-0.702	-2.664	0.531	-1.982
Railroad eqmt	3743	0.619	-1.153	0.389	1.027
Guided missiles and space veh.	376	0.972	0.968	0.751	-0.025
Misc. transportation	379A	4.114	0.513	-0.889	0.223
Engrg,lab,scientific eqmt	3811	-0.663	1.369	0.555	0.706
Measuring and controlling instr.	382	-0.794	0.614	-0.480	0.998
Optical instr., ophthalmic goods	383A	-0.451	1.072	0.824	-0.916
Surgical,medical and dental instr.	384	-0.924	0.611	-0.335	0.594
Photographic eqmt and supplies	3861	-0.659	1.234	-0.391	-0.520
Watches,clockwork operated devices	3873	-0.699	0.077	-1.678	-0.558

Table A.4 Rotated factor pattern matrix
(Extraction, principal axis; rotation, varimax)

Machine tool type	Factor 1	Factor 2	Factor 3	Factor 4
BR	.80058			
HON	.72432			
MM	.67532			
GRT	.67262			
ST	.65751			
B	.63781			
NCB	.62026		.35138	
GEAR	.58983			
NCM		.70146		
MB		.65655		-.32907
NCMC		.62801	.46523	
GOT	-.31923	-.62087		
LTS	-.31217	.60681		
DR		-.53079	.51798	
NCL			.70118	.40308
DB	-.43786		-.58448	
LTA			.50890	
NCD			.36996	
LTAC				.75608
DM				.70635
LTT			.48088	.63444
GFS				-.44701

Table A.5 Rotated factor structure matrix
(Extraction, principal components; rotation, oblimin)

Machine tool type	Factor 1	Factor 2	Factor 3	Factor 4
BR	.81420	-.34366		
HON	.76251			
GRT	.73554			
B	.71969			
NCB	.69717		.38646	
MM	.69004			
GEAR	.66174			.32508
ST	.64708	-.30050		.43314
DB	-.52336	.31483	-.48371	.40417
NCM		.73920		
MB		.73613		-.37424
LTS	-.38949	.70709		
DR		-.65614	.53119	
GT		-.64700		
NCL	.30951		.81148	
LTT			.62254	.48959
NCMC		.53817	.57948	
NCD			.49697	
LTA			.48911	-.39860
DM				.79221
LTAC				.78518
GFS		.33481	-.31520	-.47481

Table A.6 Factor correlation matrix of oblimin rotation

	Factor 1	Factor 2	Factor 3	Factor 4
Factor 1	1.00000			
Factor 2	-.10118	1.00000		
Factor 3	.16166	-.07117	1.00000	
Factor 4	.10294	-.12459	-.02477	1.00000

Table A.7 Industry classification used in factor analysis

Industry name	Legend	SIC classification (SIC 3 or 4 digit)
Metal cans and shipping con.	341	All
Cutlery, hand tools & gen.hardware	342	All
Heating eqmt and plump. fixtures	343	All
Fabricated str. metal products	344	All
Screw machine products	345	All
Metal forgings	346A	3462 and 3463
Metal stampings	346B	All others in 346
Coating, engraving and other ser.	347	All
Ordnance and accessories	348	All
Misc. fabricated metal products	349	All
Engine and turbines	351	All
Farm and garden machinery and eqmt	352	All
Construction, mining eqmt	353A	3531, 3532 and 3533
Materials handling mach. and eqmt	353B	All others in 353
Machine tools	354A	3541 and 3542
Other mtwrkng mach.,eqmt and acc.	354B	All others in 354
Special industrial machinery	355	All
General inds. mach. and eqmt	356	All
Office,comp. and account. machines	357	All
Refrigeration and serv. ind. eqmt	358	All
Misc. machinery, except electrical	359	All
Elec. trans. and distr. eqmt	361	All
Electrical industrial apparatus	362	All
Household appliances	363	All
Elec. lighting and wiring eqmt	364	All
Radio and TV eqmt	365	All
Communications eqmt	366	All
Electronic components and acc.	367	All
Misc. elec. mach. and eqmt	369	All
Complete motor vehicles	371A	All except 3714
Motor vehicle parts and acc.	371B	3714
Complete aircraft	372A	3721
Aircraft engines and parts	372B	All others in 372
Ship and boat building and repair.	373	All
Railroad eqmt	3743	All
Guided missiles and space veh.	376	All
Misc. transportation	379A	375 and 379
Engrg,lab,scientific eqmt	3811	All
Measuring and controlling instr.	382	All
Optical instr., ophthalmic goods	383A	383 and 385
Surgical, medical and dental instr.	384	All
Photographic eqmt and supplies	3861	All
Watches,clockwork operated devices	3873	All

CHAPTER 4

TECHNOLOGICAL CHANGE IN MACHINE TOOLS AFTER 1975 AND THE U.S. MACHINE TOOL INDUSTRY

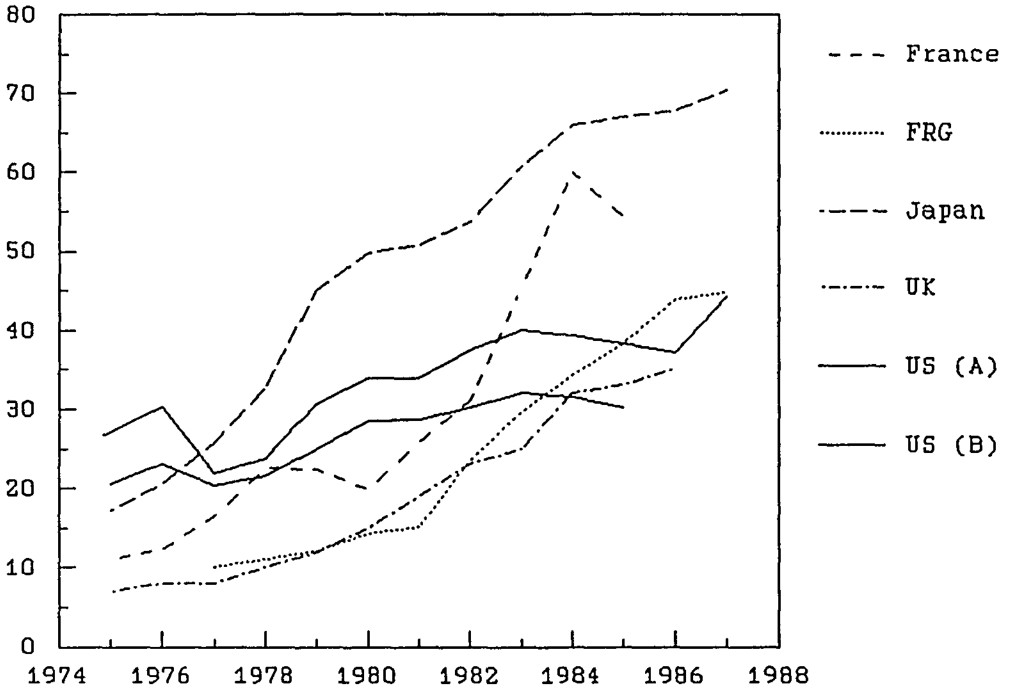
4.1. Introduction

This chapter analyzes the recent changes in metalworking technologies, and the reaction of the U.S. machine tool industry and its various segments to these changes. The purpose is to shed light on two critical arguments: i) flexible manufacturing technologies are in the focus of recent changes in machine tool technology, and ii) U.S. machine tool producers are less competitive in these areas because of their long commitment to mass production technology. The chapter is organized as follows. Recent changes in manufacturing systems are analyzed in Section 4.2 by using the results of Chapter 3. The reaction of the U.S. machine tool industry to these changes and its international competitiveness in various segments of machine tools are examined in Section 4.3. Section 4.4 concludes the chapter.

4.2. Changes in the Manufacturing Systems after the mid-1970s

As described in the preceding chapter, one of the most important technological developments in machine tools in recent years is the widespread diffusion of NC machine tools. There are many studies on the diffusion of NC machine tools. Some of these studies are concentrated on the characteristics of firms or industries that facilitate or obscure the diffusion process (see Ray, 1984: 60-73; Romeo, 1975; Globerman, 1975; Liberatore and Titus, 1986). A recent study by Edquist and Jacobsson (1988) documents in detail the increasing share of flexible automation technologies (NC machine tools, robots, CAD/CAM equipment, etc.) in many developed and less developed countries. Thus, for the purpose of this study, suffice it to state the fact that the production of flexible automation equipment (and, above all, NC machine tools) has increased dramatically in almost all major producer countries after 1975 when the first microprocessor-based NC machine tool was developed. Figure 4.1 depicts the share of NC machine tools in total machine tool production for six developed market economies during the period 1975-1987. The production of NC machine tools grew rapidly in all countries except the U.S. Incidentally, the U.S. had the highest share of NC machine tool production in the early years of this period. Note also that two other major producer countries, Italy and Switzerland, whose complete data set for this period could not be obtained, have high NC machine tool production shares.

Figure 4.1 Share of NC machine tools in total machine tool production of major producer countries, 1975-1987



Notes: For Japan, the share of NC metalcutting machine tools in total metalcutting machine tools is depicted. US (A) represents the share of NC metalcutting machine tools in total metalcutting machine tool production, and US (B) the share of NC machine tools (metalcutting plus metalforming) in total machine tool production for the U.S. Since the use of NC equipment is normally diffused more into metalcutting machine tools, the share for total is somewhat lower than that of metalcutting machine tools.

Sources: France: NMTBA, *Handbook 1985-1986*; FRG: VDMA, *Werkzeugmaschinen-Statistik, 1987*; Japan: *Metalworking Engineering and Marketing*, related issues; U.K.: MTTA, *Machine Tool Statistics, 1985*; U.S.: DoC, *Current Industrial Reports: Metalworking Machinery*, Series MQ35W, related issues. Prior to 1978, the shares of NC grinding and NC milling machines were estimated by using historical trends. (Their combined total share was less than 4% during that period.)

The increase in the production of NC machine tools does not directly reflect any transformation in the relationships between the relative importance of manufacturing systems in the engineering industries. NC machine tools may be simply replacing conventional, general purpose machine tools in these fields instead of enlarging the scope of flexible, low-volume/high-variety production. Thus, a direct comparison between the manufacturing systems should be made to assess relative shifts in their use.

The machine tool stock data on which the factor analysis is based are available only for 1983 by the '13th American Machinist Inventory of Metalworking Equipment'. Unfortunately, previous surveys of the American Machinist (the 12th inventory covers 1976-1978 stock) are not comparable to the 13th survey because of differences in machine tool classifications used in those surveys. Therefore, a direct comparison of relative changes in the use of manufacturing systems between survey years could not be accomplished. (The 14th survey, hopefully available at the end of 1989, can be used to combine data from the 13th survey for a new factor analysis covering both periods.) Instead, indirect comparisons can be made by analyzing modernization ratios of manufacturing systems, and changes in the machine tool production structure.

Table 4.1 **Modernization ratios for manufacturing systems**

Factor	Manufacturing system	Modernization ratio
1 TLINE	'Transfer lines'	10.9%
2 CELL	'Manufacturing cell'	29.4%
3 FMS	'Flexible manufacturing systems'	35.4%
4 SPEC	'Special systems'	12.1%

Table 4.1 depicts the weighted average modernization ratios[1] of manufacturing systems found by factor analysis. As may be expected, the highest ratio is found for the third factor that is interpreted to represent flexible manufacturing. The ratio for CELL factor is also significantly higher than those of TLINE and SPEC.

As long as there are not any strong systematic differences in the depreciation rates and price increases for each manufacturing system, the modernization ratios may show the changes in emphasis on various manufacturing systems in recent years. The modernization ratios shown in Table 4.1 reveal a trend toward increased use of 'manufacturing cells' and 'flexible manufacturing systems' after the late-1970s in the U.S.

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[1] Modernization ratio is defined as the share of 0-4 years old machine tools in total. Factors' modernization ratios were found by weighting each machine tool's ratio by that coefficient in the factor score coefficient matrix which is used to find the factor score matrix from the data matrix (original variables). In matrix notation, $m_f = Q'm_v$, where m_f is the 4x1 vector of average weighted modernization ratios of factor scores, m_v is the 22x1 vector of machine tools' modernization ratios, and Q is the factor score coefficient matrix.

Shares of some types of machine tools in total machine tool production in value terms are shown in Figures 4.2-4.6 to supplement the information revealed in the modernization ratios. Since it is not possible to obtain complete time series for all machine tool types used in the factor analysis due to the disclosure rules, a breakdown of machine tools by manufacturing systems could not be done as in Figures 3.3-3.6.

Figures 4.2 and 4.3 show trends in the machine tools mainly used in mass production systems whereas Figure 4.4 shows trends in NC machine tools.[2] There are profound decreases in the share of automatic-chucking machines (LTAC), automatic bar machines (LTAB) (both machines are types of lathes), and multi-spindle drilling machines (DM). Other types of mass production machine tools show irregular cyclical disturbances. Since their shares in total production are relatively low, it becomes difficult to reach strong conclusions. A surprising result is exposed for the most important (both in qualitative and quantitative terms) mass production equipment, station-type (ST) machines. The share of this machine which is almost equal to the total value of all other mass production machine tools shown in Figures 4.2 and 4.3 does not show any tendency to increase or decrease, but the fluctuations in its share are large.

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[2] Because of the disclosure rules, data for some types of machine tools are not available for all years covered in these tables.

Figure 4.2 Shares of mass production machine tools in total machine tool production in the U.S. (in percent)

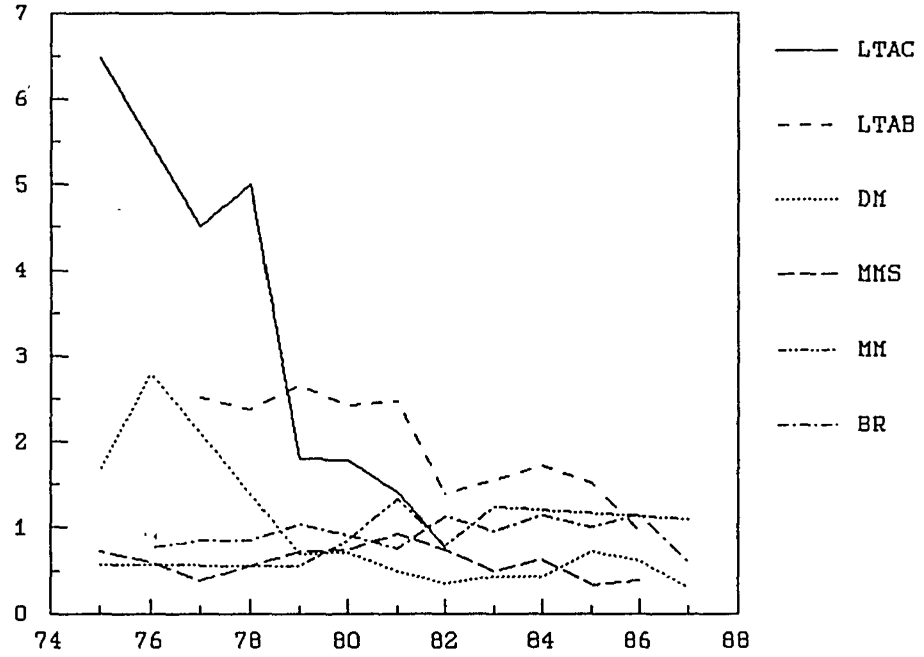


Figure 4.3 Shares of mass production machine tools in total machine tool production in the U.S. (in percent)

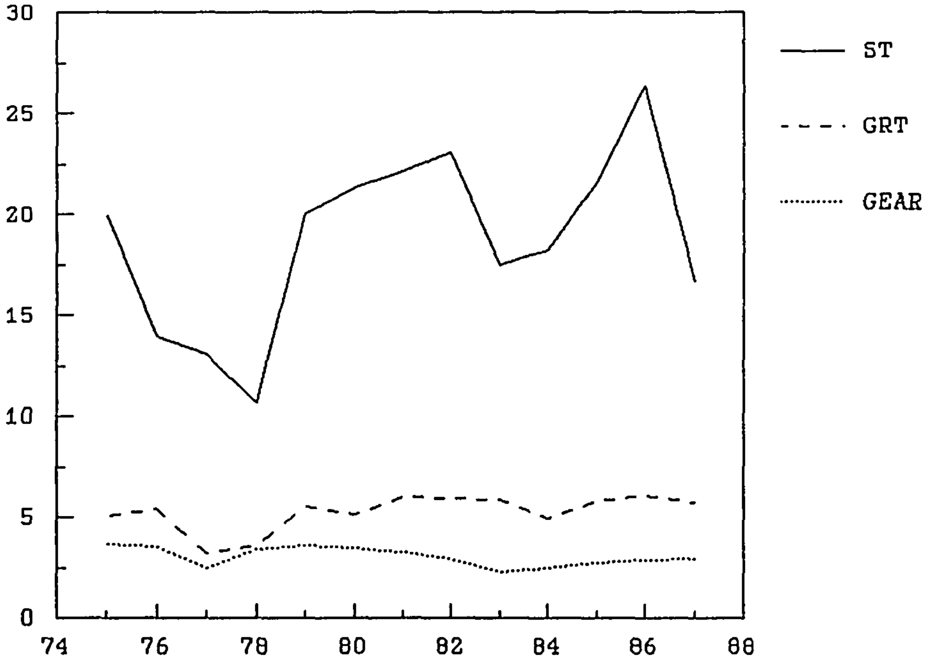


Figure 4.4 Shares of NC machine tools in total machine tool production in the U.S. (in percent)

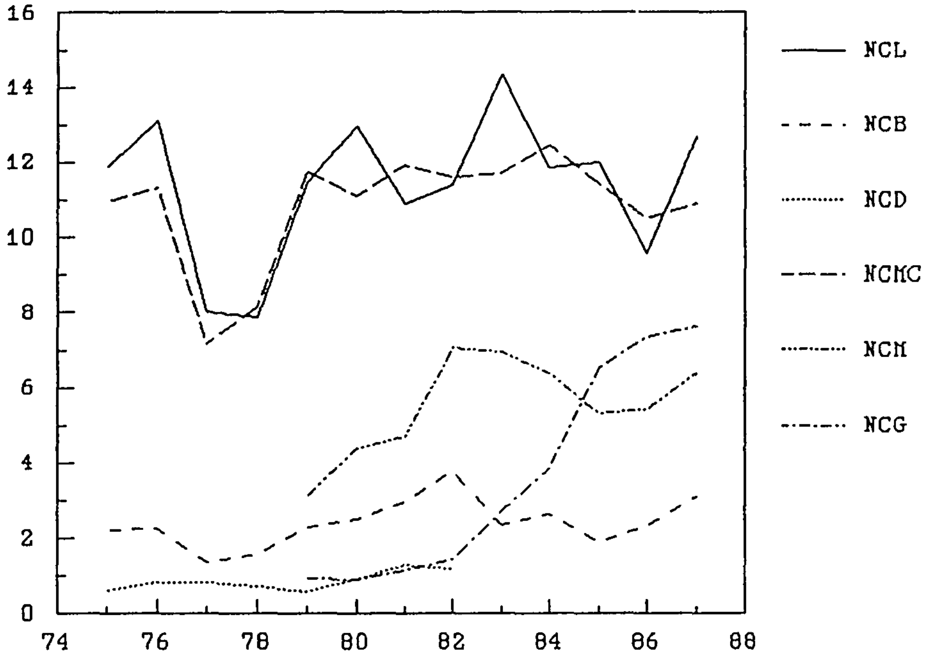


Figure 4.5 Shares of mass production machine tools in their respective operation type in the U.S. (in percent)

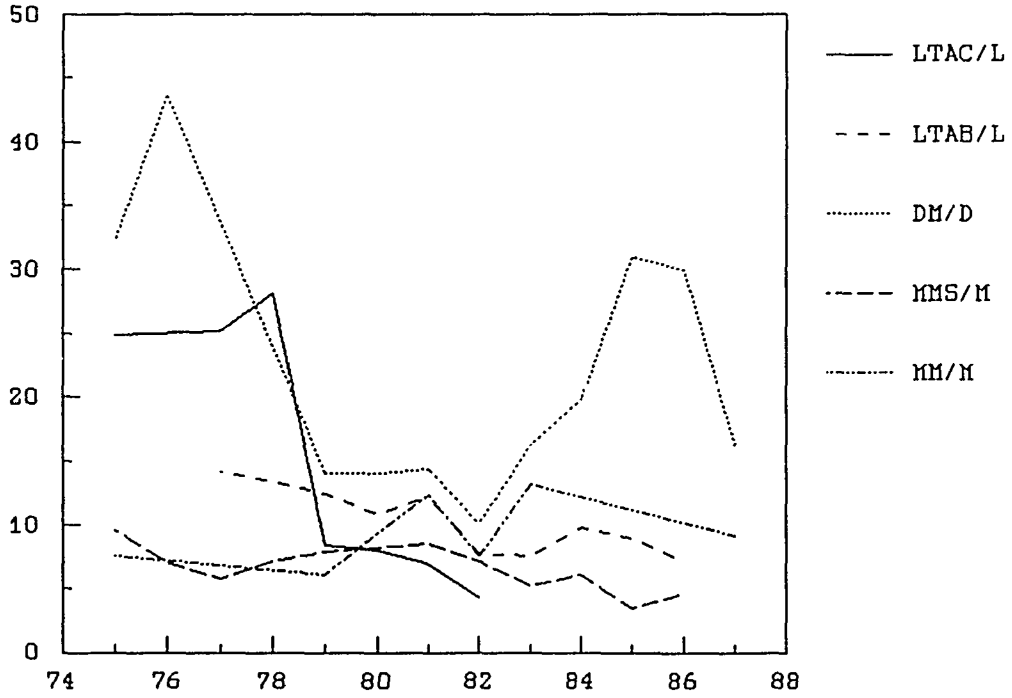
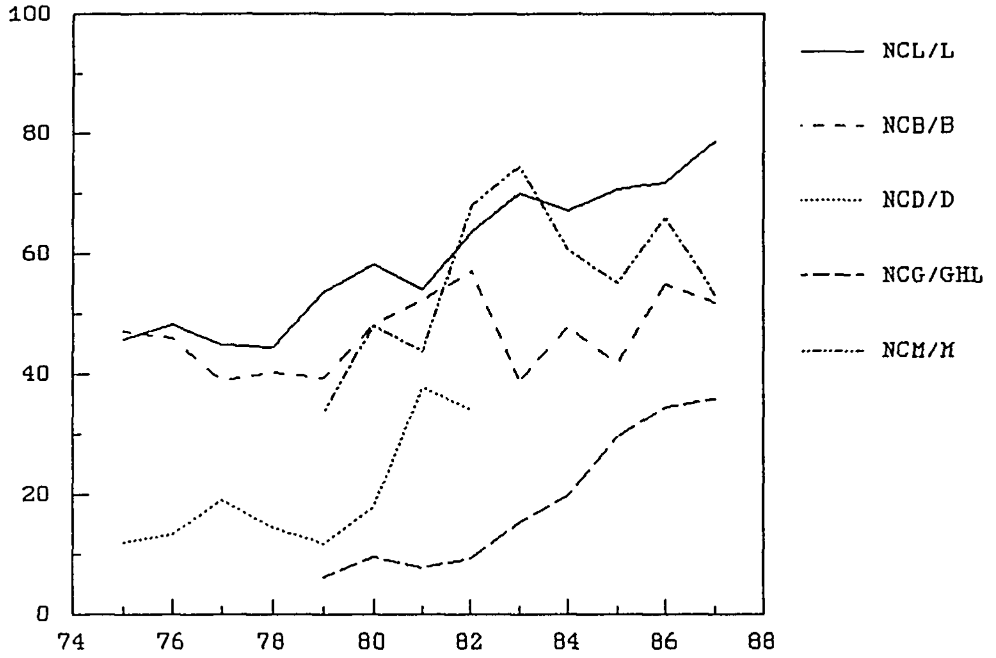


Figure 4.6 Shares of NC machine tools in their respective operation type in the U.S. (in percent)



As shown in Figure 4.4, shares of NC machine tools in total U.S. machine tool production are increasing or constant. The highest increases are achieved by NC grinding and milling machines.

The structure of machine tool production changes in the course of industrial development. It is a well-known fact that the shares of simple machine tools such as engine lathes and drilling machines decrease whereas the share of grinding machines increases. Therefore, it is also important to examine the shares of machine tools in their respective operation types (drilling, turning, etc.) by their machine control functions. Figure 4.5 and 4.6 illustrate the shares of mass production and NC machine tools in their operation types, respectively. (For example, LTAC/L means the share of automatic chucking machines in total lathe production.) These figures let us deduce stronger conclusions on the relationships between various types of machine control technologies.

The shares of almost all mass production machine tools in their respective operation type are decreasing whereas the opposite is true for the NC machine tools. In other words, for those machine tools that can be controlled by both flexible (NC) and 'hard' automation technologies, the flexible automation tends to become a dominant mode of control. But, recall that these figures should be valued together with Figures 4.2 and 4.3 because some machine tools are controlled only by 'hard' automation almost by definition. The most important type of this group, station-type machines, as shown in Figure 4.3, have not shown any tendency to lose share in total machine tool production in the U.S.

Having established the fact that the share of flexible manufacturing and cell systems are increasing in the U.S. engineering industries, the effects and extent of these changes can be comprehended. There are two opposing views on the interactions between flexible automation and mass production technologies.

Piore and Sabel, based on a 'meta-history' of manufacturing from the beginning of the Industrial Revolution to recent times, claim that there is a deterioration in economic performance in the last couple of decades and that this deterioration 'results from the limits of the model of industrial development that is founded on mass production.' (Piore and Sabel, 1984: 4) Mankind is now living through the second industrial divide between two different models of industrial development. On the one hand, there is mass production which is characterized by 'the use of special purpose (product specific) machines and of semi-skilled workers to produce standardized goods.' On the other hand, there is flexible specialization which is 'based on flexible -multi-use- equipment; skilled workers; and the creation, through politics, of an industrial community that restricts the forms of competition to those favoring innovation' (Piore and Sabel, 1984: 4, 17). The technological structure of flexible specialization has been laid down by recent developments in flexible manufacturing technologies such as NC machine tools, FMSs, etc. Although the choice between these two alternative economic paradigms is not pre-determined because of complex economic and political factors, Piore and Sabel seem to prefer flexible specialization as a more efficient, flexible and humane alternative.

On the other side of the spectrum, some researchers argue that the implications of recent developments in manufacturing technologies are not so dramatic. For example, Williams et.al (1986) say, in their critique of Piore and Sabel's book, that Piore and Sabel could not show any evidence to support their hypothesis, and, moreover, grossly overestimated the current problems of mass production industries and the 'flexibility' implications of new technologies. As evidence of the latter argument they show the use of FMSs in large companies and the need to attain high cumulative volume of production by FMSs to ensure their full utilization and economic justification. In a similar way Thompson (1986: 61) says that 'suggestive though this idea of "flexible specialization" is, it is problematical on at least three major counts. In the first place ... FMS need not imply the break up of the large factory or the end of mass-production of standardized components or products. They allow for "batch production" and are hence flexible in this sense but do not imply any necessary undermining of mass-production technology as such.' Secondly the emphasis on 'flexibility' is nothing but a temporary response to the economic recession of the late 1970s and early 1980s. 'The pressure for "flexibility" may therefore be worth resisting' since promoting 'flexible specialization' at the expense of standardized mass-production as a *general* mechanism of economic organization could lead to a weakening of the competitive position in the long run. Finally there is not much evidence, according to Thompson, for the argument about 'flexible specialization' displacing 'mass production' in the advanced industrialized countries.

Thompson uses FMS in a narrow, technical sense in his article. The concept of FMS proper as a set of CNC machine tools, automated materials handling and transfer equipment, and a centralized computer control was oversold at the beginning of its development by the industry. It has failed to satisfy all of the raised expectations about 'volume' and 'flexibility'. The majority of FMS proper currently operated (at least in the U.S. and Europe) should have large *total* output and be used almost 24 hours a day to be justified (Sciberras and Payne, 1985: 27). Moreover, they are not as flexible as it was thought (for examples, see Bessant and Haywood, 1988: 355, and Zygmont, 1986). Even in the case of NC machine tools, in a survey of the diffusion of NC machine tools, 'the overwhelming majority of non-NC users cited too short production runs as a very important reason for non-adoption' (Globerman, 1975: 433).

The concept of FMS is used in a broader sense in this study. Accordingly, the major questions raised by Thompson that is summarized here are on the temporariness of the emphasis on flexibility as a result of economic crisis, and the existence of evidence for the argument about 'flexible automation' displacing 'mass production' in the advanced industrialized countries.

If there is a general tendency toward the replacement of mass production systems by FMS in some segments of volume/variety combinations, the ratio of mass production systems to FMS may be expected to decline after the mid-70s due to the development of flexible automation technologies. Moreover, if the emphasis on flexibility is a result of economic recession, its relative share may be expected to expand in recessionary periods because of the expectations of economic agents and the possibilities of incremental investment in FMS.

Figure 4.7 Changes in the ST/NC ratio, and metalcutting machine tool production and apparent consumption in the U.S.

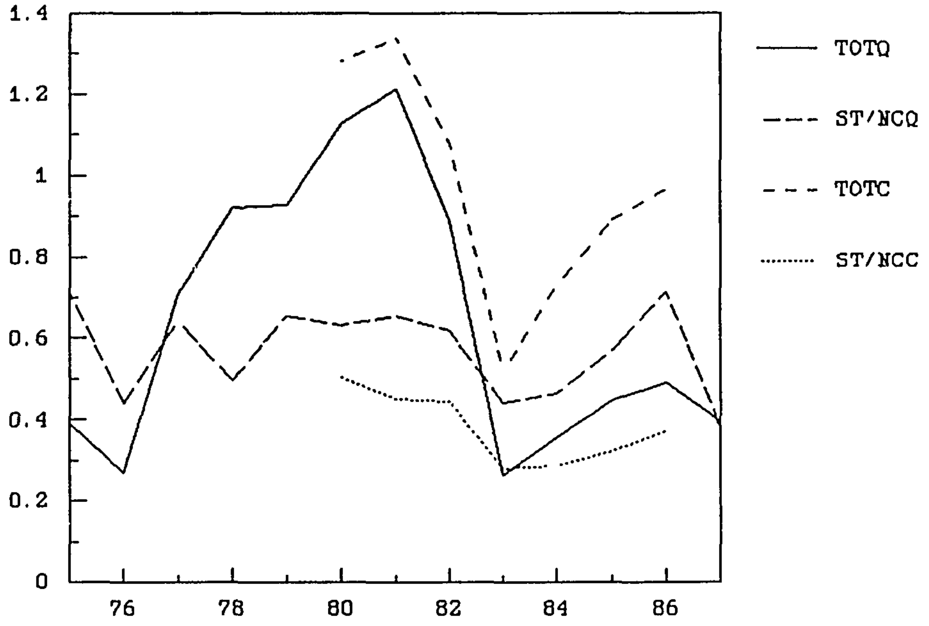
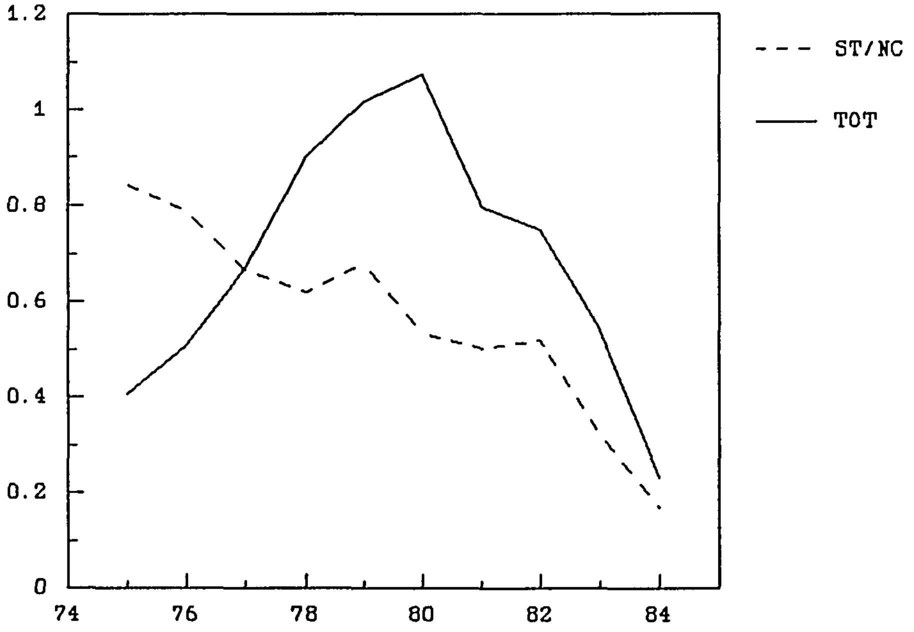


Figure 4.8 Changes in the ST/NC ratio, and metalcutting machine tool production in the U.K.



Figures 4.7 and 4.8 depict changes in the ratio of station-type machines to NC metalcutting machine tool production (ST/NC), and total metalcutting machine tool output (TOT) for the U.S. and the U.K.[3] In these figures, station-type machines and NC machine tools are used to represent mass and flexible manufacturing systems. Total metalcutting machine tool output figures are in logarithmic form. For the U.S., ST/NC and TOT values are also distinguished between production (suffix Q), and apparent consumption (suffix C). (Since there is a change in trade classification of machine tools used by the Department of Commerce in 1980, data on consumption are not available for ST/NC ratio prior to 1980.) To test the effects of changes in machine tool demand as a result of economic conditions, and trends in relative demand of mass production and flexible automation equipment, a simple linear model is formed as follows.

[3.1] $ST/NC_i = a_0 + a_1 TOT_i + a_2 TIME_i + e_i$, where ST/NC is the ratio of production of station-type machine tools to that of NC metalcutting machine tools, TOT total metalcutting machine tool production, and subscript 'i' denotes time. For the U.S., suffix 'C' and 'Q' represent consumption and production, respectively.

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[3] For the U.K., 'station-type machine' is used to mean 'unit construction and transfer machines' as defined in the U.K. statistics. Up to 1978, 'unit heads' were not included in this category, i.e., figures for 1975-1977 slightly underestimate this variable. This variable is not strictly comparable for the U.S. and U.K. because of the differences in definitions. For data sources, see Figure 3.7.

Table 4.2 Determinants of relative demand for station-type and NC machine tools in the U.S.

	Dependent variables (time period)							
Variables	ST/NCQ (75-87)	ST/NCQ (75-87)	ST/NCQ (75-87)	ST/NCQ (76-87)	ST/NCQ (76-87)	ST/NCC (80-86)	ST/NCC (80-86)	ST/NCC (80-86)
TOTQ	.16* (1.74)	.15* (1.57)		.20** (2.56)	.22** (2.44)			
TOTC						.32** (5.66)	.36** (4.25)	
TIME		-.002 (-.29)	-.005 (-.59)		.003 (.42)		-.01 (-1.4)	-.02** (-2.23)
R^2	23	26	8	40	41	86	95	50

Notes: * means the coefficient is significant at the 10% level, two-tailed test.
** means the coefficient is significant at the 5% level, two-tailed test.
Numbers in parentheses are t-values.
This notation is used in all tabulated regression results.

Table 4.3 Determinants of relative demand for station-type and NC machine tools in the U.K.

	Dependent variables (time period)			
Variables	ST/NC (75-84)	ST/NC (75-84)	ST/NC (77-84)	ST/NC (77-84)
TOT	.19 (.72)	.13* (1.67)	.53** (3.43)	.46** (2.35)
TIME		-.06** (-9.13)		-.04** (-3.90)
R^2	6	93	66	92

Figure 4.9 Regression plot of total metalcutting machine tool production (TOT) by ST/NC ratio for the U.S.

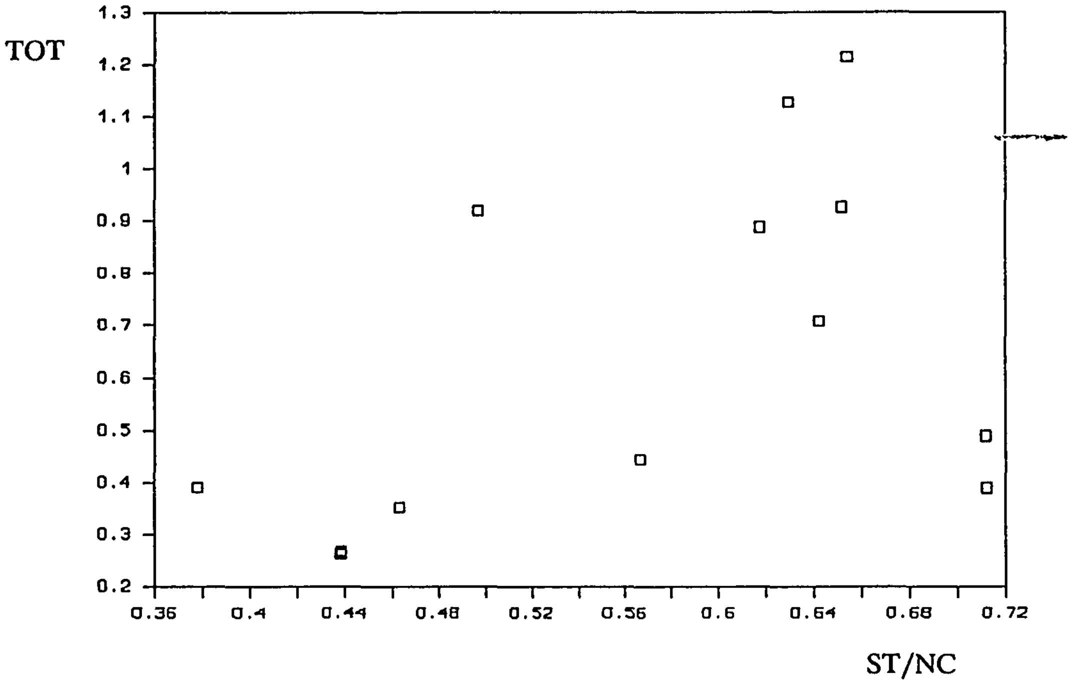
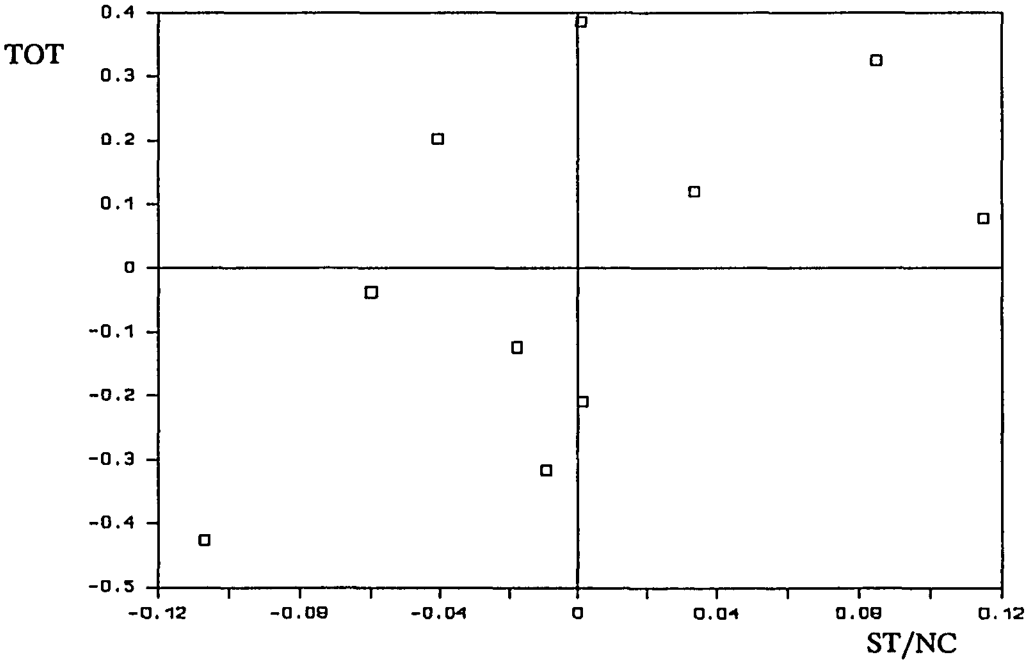


Figure 4.10 Partial regression plot of total metalcutting machine tool production (TOT) by ST/NC ratio for the U.K.



The results of the regression estimates are shown in Tables 4.2 and 4.3, and regression plots of TOT by ST/NC are depicted in Figures 4.9 and 4.10. (For the U.K., partial regression plots are depicted since the TIME variable is also significant.) These results show that there is a statistically significant relation between ST/NC ratio and total machine tool output (and consumption) for both the U.S. and the U.K., i.e., an increase in machine tool production (demand) as a result of improved economic conditions leads to an increase in the share of mass production machines relative to NC machine tools. Moreover, there is not any significant tendency in the ST/NC ratio to decline for the U.S. case, whereas it is apparent in the U.K.[4] (see Figures 4.7 and 4.8).

In brief, the following conclusions can be obtained from our analysis on the relationships between flexible manufacturing and mass production systems.

i) For all major machine tool producer countries, NC (and, hence, flexible manufacturing) technologies are increasing in their importance in metalworking processes as shown in their increasing share in machine tool production in Figure 4.1. It seems that this increase in the share of NC machine tools is mainly a result of replacement of general-purpose,

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[4] The decrease in the ST/NC ratio in the U.K. comes from the rapid increase in NC machine tool production. During this period, there is not any significant change in the share of ST machines in total metalcutting machine tool production. Throughout this period the share of ST machines has fluctuated around 10% in the U.K., and 20% in the U.S.

conventional machine tools, and, to some extent, mass production technologies.

On the other hand, highly integrated types of mass production machinery, e.g., station-type machines, seem to be less affected by the diffusion of flexible technologies. Thus, in the U.S., the ratio between production of station-type machines and NC machine tools does not decrease rapidly, whereas the decrease in this ratio in the U.K. is very significant. This may be as a consequence of country-specific characteristics (the size of the domestic market, relative technological competence in mass production machinery and NC machine tool producers, etc.). Accordingly, a drastic decline in this ratio for Japan could be expected, although similar data are not available.[5]

ii) The second result of this analysis is the dependence of relative changes in the use/production of mass production and flexible manufacturing systems on the level of machine tool demand, and, presumably, general economic conditions. This result supports the argument that the recent emphasis on flexible manufacturing is partially a result of economic crisis continuing during the last decade. Consequently, it may be expected that a new period of economic growth and stability in economic conditions may

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[5] These differences can be seen in the attitudes of U.S. machine tool users toward manufacturing systems. For example, according to E.M. Nelson, executive director for manufacturing on the Engineering and Manufacturing Staff of Ford Motor Co., 'traditional transfer-line machining concepts are expected to be in demand for a long time, but in improved, modified forms' (Wrigley, 1987: 12).

rejuvenate the production of mass production machinery. This possibility is also strengthened by the fact that mass production machinery has begun to reap the (indirect) benefits of new computerized technologies through two different channels: first, 'hard' controls of mass production machinery are increasingly replaced by 'soft' controls (programmable controllers, etc.), and, second, it becomes less expensive to manufacture special-purpose, custom-made mass production machinery as a result of improvements in batch production by flexible automation.

iii) Although it is not explicitly analyzed in this section, there may be significant inter-industry differences in the use of manufacturing systems. It can even be said that mass production and flexible manufacturing technologies should coexist in various industries because the widespread use of mass production machinery in some industries means extensive complementary use of flexible manufacturing systems for the manufacturing of certain custom-made, low-volume items.

4.3. International Competitiveness of the U.S. Machine Tool Industry

In the preceding section, the trends in the production of various types of machine tools that form manufacturing systems are analyzed for the U.S. In this section, the international competitiveness of the U.S. machine tool industry in each machine tool type is explored. But a general picture of the U.S. machine tool industry should be presented before this detailed analysis.

Figures 4.11-4.13 depict trends in machine tool production for major developed market economies.[6] The output values in Figure 4.11 are given in U.S. dollars, enabling us to compare the size of the industry in each country. As shown in this figure, the U.S. leadership in machine tool production has declined drastically during the 1980s. In 1988, in spite of 'optimistic' expectations inspired by continuous decline in the value of the U.S. dollar, the U.S. machine tool industry has not been able to increase its output share and it fell behind three other market economies (namely, Japan, FRG, and Italy) for the first time of its post-war history.

Figure 4.12 shows production indices (1980=100) based on output figures in U.S. dollars, and Figure 4.13 shows production indices (1980=100) based on output figures in local currencies to reflect the effects of fluctuations in exchange rates. In both figures, the rapid decline in the growth rate of the U.S. machine tool production is apparent. In terms of output values based on U.S. dollar and local currencies, all countries have reached or surpassed 1980/81 levels (1981 was peak for Japan and the U.S., 1980 for all others). The only exception is the U.S. which experienced more than a 50% decline in machine tool production after 1980.

The break in the tempo of machine tool production between the U.S. and other developed market economies is evident in Figures 4.12 and 4.13. As

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[6] *American Machinist* is the data source for Figures 3.17-3.22. In Figure 3.19, machine tool production in local currencies is found by using exchange rates given in IMF, *International Financial Statistics.*

these figures show, the U.S. machine tool industry is not anymore inside the cluster of major producers during the 1980s in terms of the growth in machine tool production.

Figures 4.14 and 4.15 reveal information about the peculiar aspects of the international participation of the U.S. machine tool industry. As shown in Figure 4.15, the export-output ratio of machine tools (X/Q) for the U.S. is very low and there is almost no change in this ratio throughout the 1970s and 1980s. Note that, in spite of the emergence of some less developed countries as machine tool producers, the export-output ratio of machine tools for the world[7] as a whole has been increasing in the last two decades. This ratio was 28.9% in 1965, and it has been higher than 45% in the late-1980s. The increase in this ratio demonstrates the development of international specialization in machine tool production at the global scale.

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[7] By 'world', we mean major machine tool producer countries (some 30 countries) that produce almost all of world machine tool output, as given in *American Machinist* magazine.

Figure 4.11 Machine tool production in developed market economies (in million U.S. $)

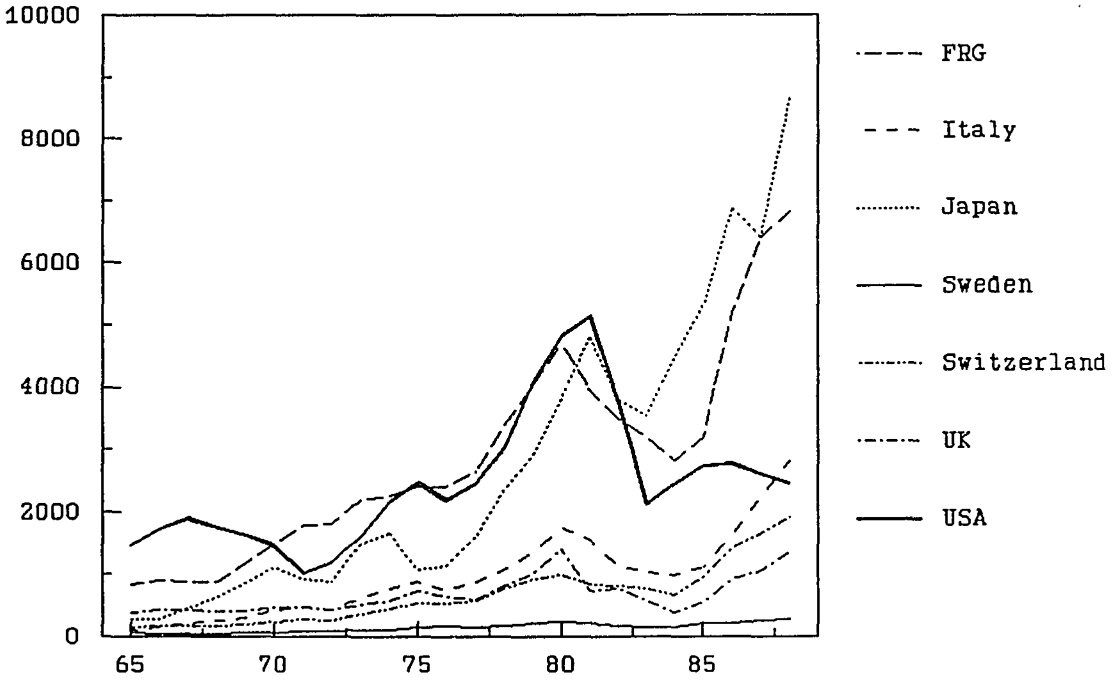


Figure 4.12 Machine tool production indices for developed market economies (1980=100, based on U.S. $)

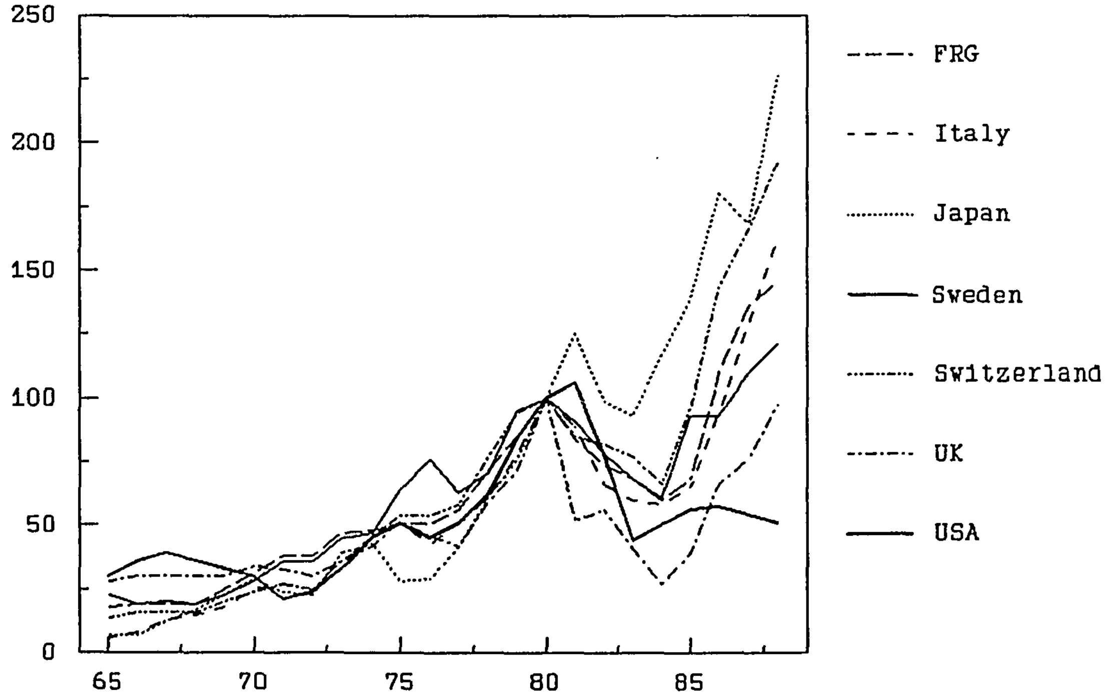


Figure 4.13 Machine tool production indices for developed market economies (1980=100, based on local currencies)

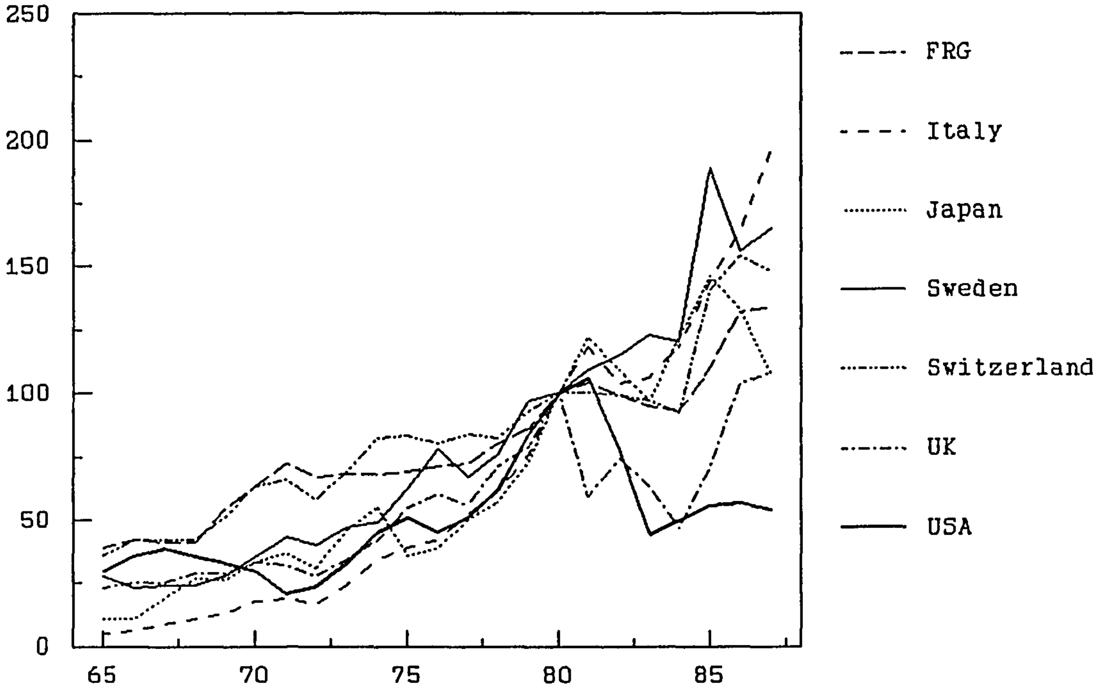


Figure 4.14 Import penetration ratio (M/Q+M-X) in machine tools for developed market economies

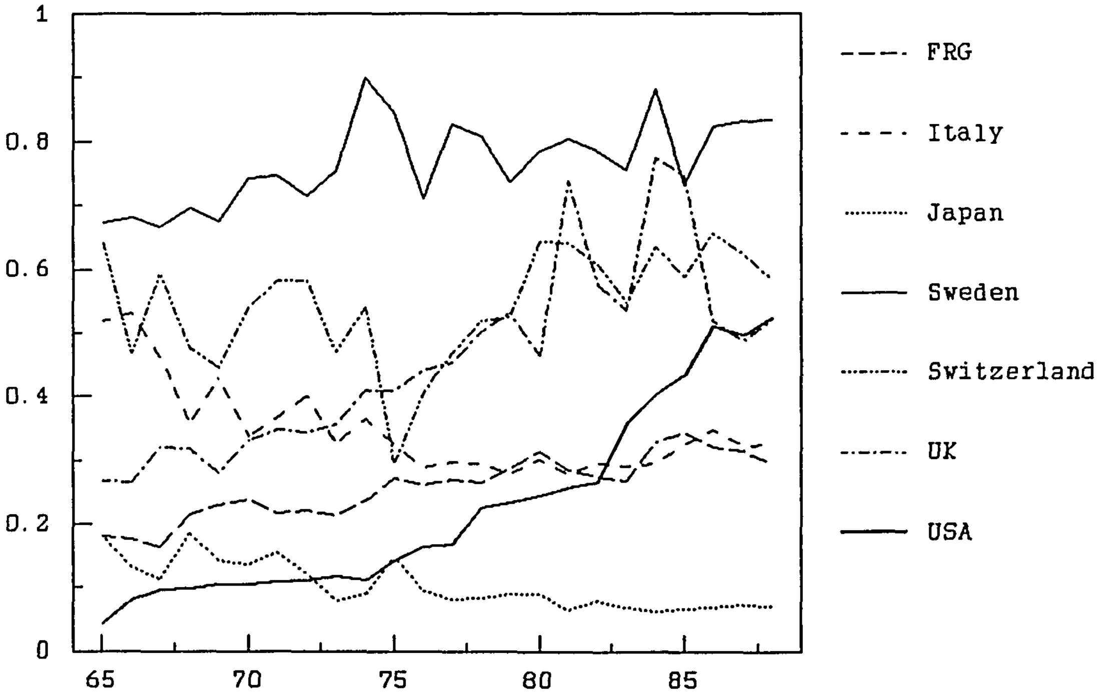


Figure 4.15 Export ratio (X/Q) in machine tool for developed market economies

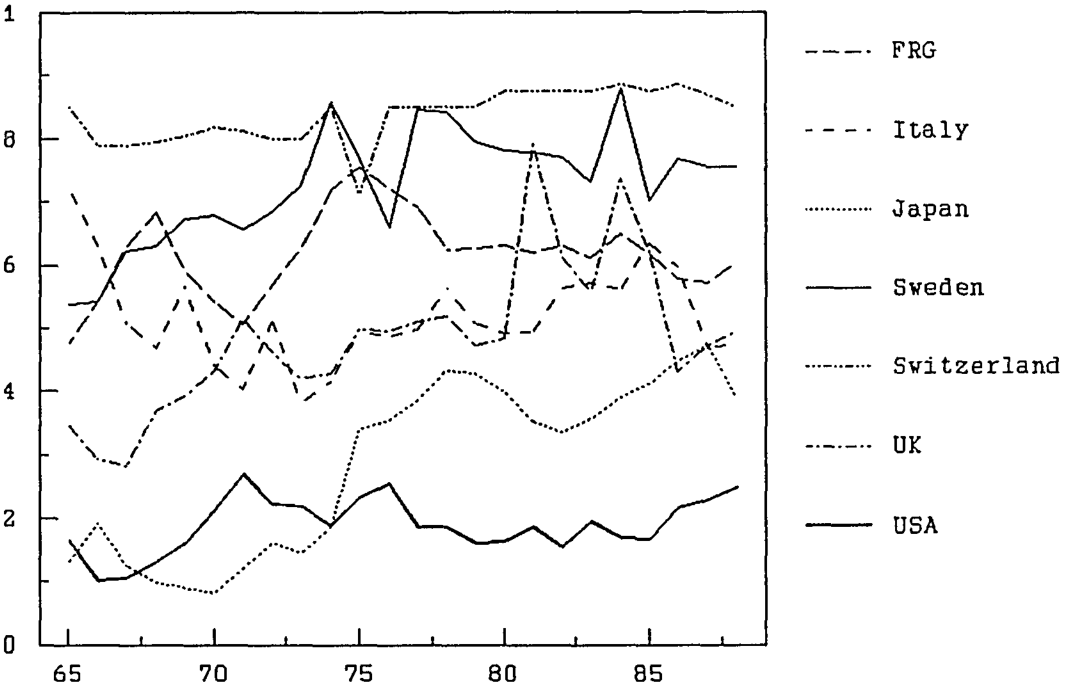
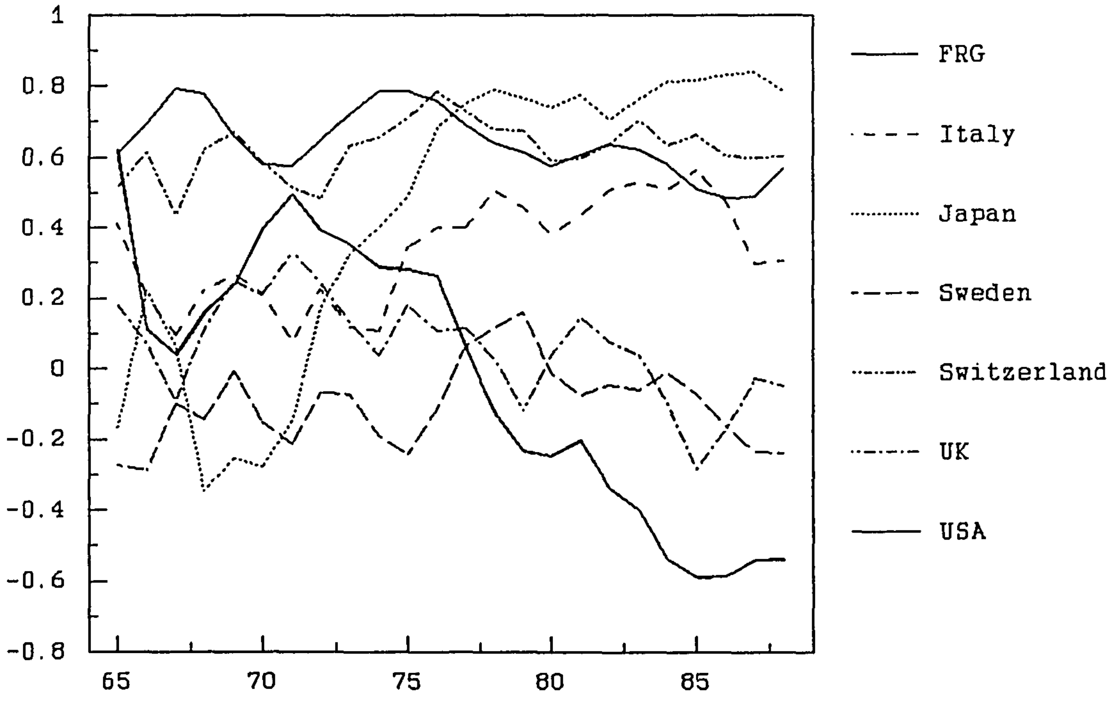


Figure 4.16 Net export ratio (X-M/X+M) in machine tool for developed market economies



Import penetration ratios for machine tools (M/Q+M-X) are shown in Figure 4.14. In contrast to the export-output ratio, the import penetration ratio for the U.S. has been increasing after the mid-1970s. The U.K. is the only country in addition to the U.S. that experienced a rapid increase in this ratio. Note that two small countries in this group, Sweden and Switzerland, have very high export-output and import penetration ratios as a result of the highly specialized nature of their machine tool industries. Japan has an exceptionally low (and even slightly declining) import penetration ratio.

The last figure concerning the international trade position of the U.S. machine tool industry, Figure 4.16, depicts the net export ratio (X-M/X+M) that is used to represent international competitiveness of an industry.[8] The two most notable changes during the period of 1965-1988 seen in this figure are i) the rapid increase in the international competitiveness of the Japanese machine tool industry, and ii) the rapid decline in the international competitiveness of the U.S. machine tool industry starting in the early 1970s. In 1978, the net export ratio was negative for the first time for the U.S.[9] The

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[8] In this study, the net export ratio is used to measure the international competitiveness of an industry. This index is bounded by -1 (no exports) and +1 (no imports). Higher values of net export ratio is interpreted as higher competitiveness. Recall that the concept of competitiveness should also include costs (or profits) of production as well as the market share, since any firm can increase its market share to some extent by reducing its profit margin. Only market share data (net export ratio) are used to measure the international competitiveness of industries because, unfortunately, cost or profit data are not available. The lack of cost or profit data may not be a serious problem for our purposes, since net export ratio values generally show continuous trends.

[9] As may be expected, protectionist trends have been intensified in the U.S. after mid-70s. Consequently, MITI of Japan established a system of 'floor prices' for exports of Japanese machine tools to Canada and the U.S. in 1978, and to the E.E.C. in 1982 (OECD, 1983: 27).

'overvalued' U.S. dollar has been blamed for the decline of the international competitiveness of the U.S. machine tool industry, but the decreasing value of the U.S. dollar in the late-80s has not improved the competitiveness. It seems that the problems of the U.S. machine tool industry are not primarily associated with short-term changes in the exchange rate, etc. As stated in a survey of Standard and Poor's (1988: p.S-32), 'the lower dollar has apparently been more effective in restraining imports than in stimulating exports. In any event, for the foreseeable future, the U.S. will not likely regain the commanding position it once had in exports'.

But imports from Japan and other countries continued to increase. In 1983, the National Machine Tool Builders' Association submitted a petition (under the National Security Clause, Section 232 of the Trade Expansion Act of 1962) to limit machine tool imports to 17.5% level (Sprow, 1985: 43). Towards the end of 1986, the U.S. government demanded the introduction of voluntary export restraints (VER) by Japan, FRG, Switzerland, and Taiwan. Japan and Taiwan have accepted the VER, and negotiations with FRG have been partially successful (O'Brien, 1987: 29). But Switzerland refused any agreement to restrain its exports to the U.S. and stated that it would take counter-measures if the U.S. took unilateral restrictions. There was not any agreement between the U.S. and Switzerland as of January 1989 (MEM, January 1989: 55). Protectionist trends were not satisfied with these agreements. Recently, '[t]he Verson Div of Allied Products Corp, the United Auto Workers, and the United Steel Workers of America have joined in filing an antidumping petition with the Dept of Commerce. ... The filing charges that the US transfer-press-equipment industry is being hampered by unfair price competition and requests and investigation of imports from Japan' (American Machinist, Feb. 1989: 27). Moreover, some restrictions have been eased to encourage exports. For example, The National Tooling and Machining Association (NTMA) member firms are now exempted from some antitrust laws, particularly those that place curbs on the sharing of cost and price information. As a result, the NTMA is planning action to take advantage of this exemption by establishing an export trading company for its members (American Machinist, Dec. 1988: 29).

The VER agreements with Japan has partially been forced Japanese machine tool producers for foreign direct investment into the U.S. to protect and expand their market shares. For details, see O'Brien, 1987, and Miura, 1987.

Figure 4.17 Net export ratios of machine tools used in transfer lines for the U.S.

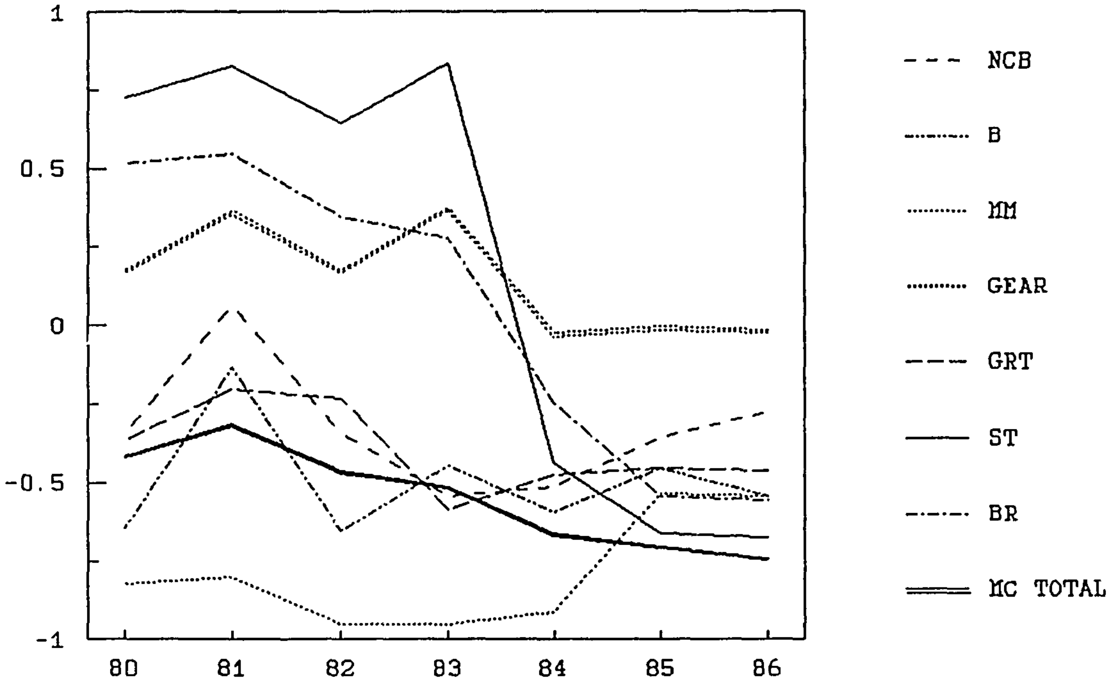


Figure 4.18 Net export ratios of machine tools used in special systems for the U.S.

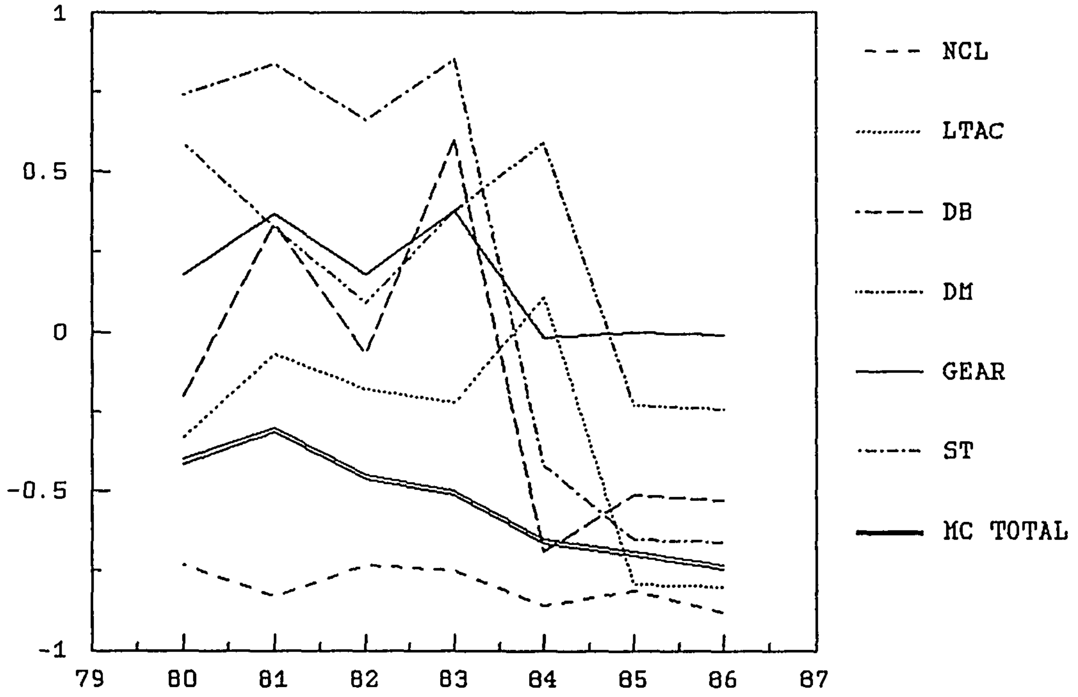


Figure 4.19 Net export ratios of machine tools used in flexible manufacturing systems for the U.S.

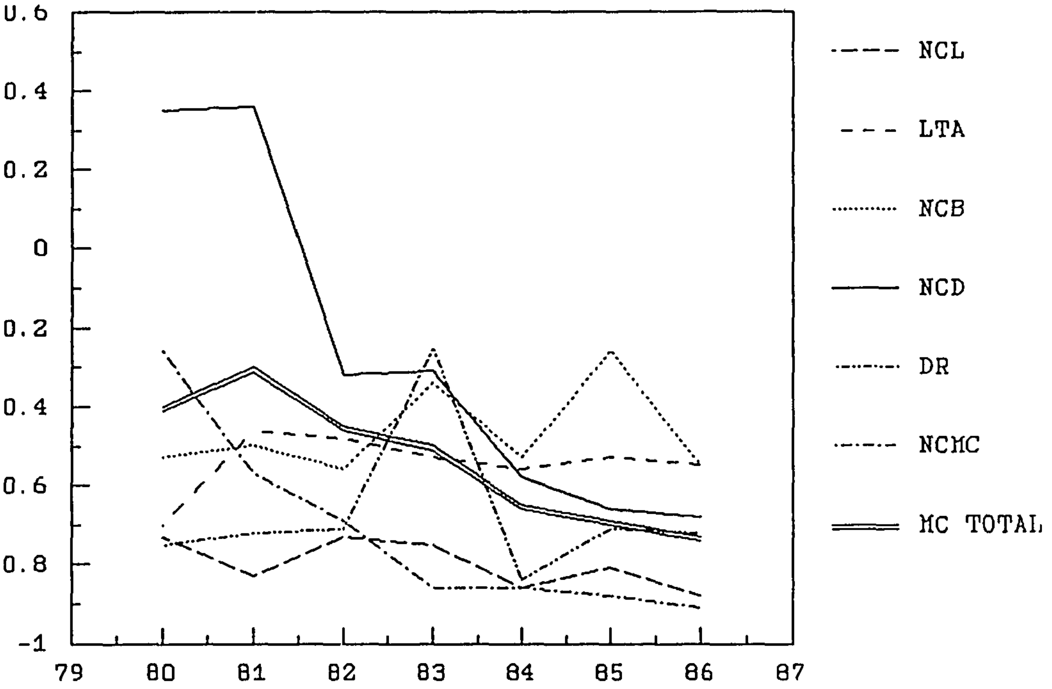
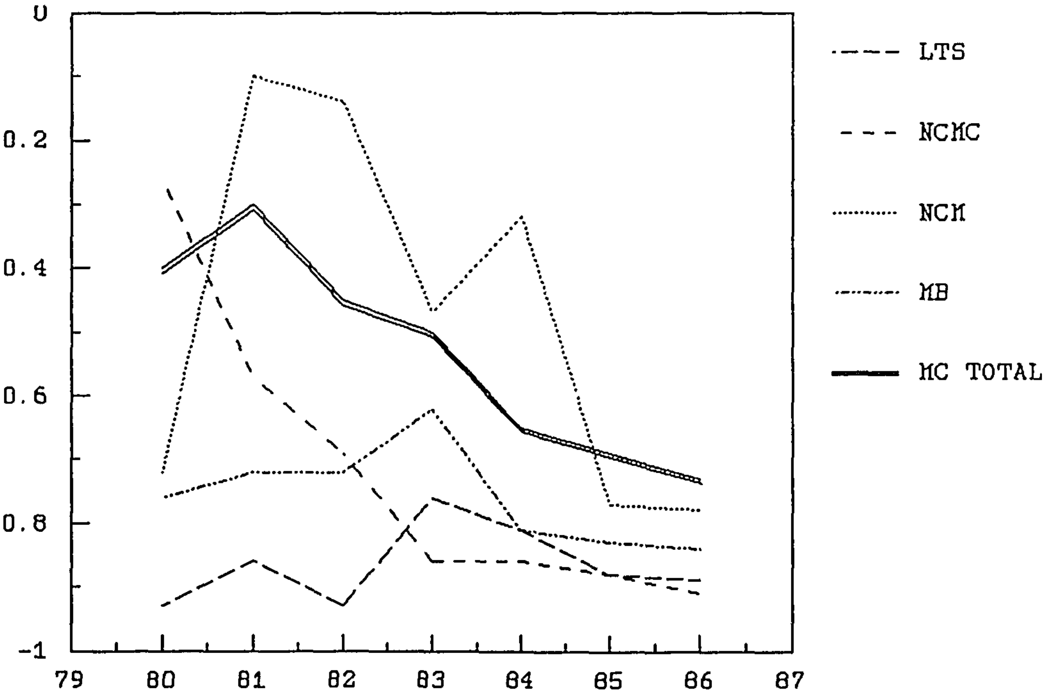


Figure 4.20 Net export ratios of machine tools used in manufacturing cells for the U.S.



The U.S. machine tool industry has been losing its international competitiveness very rapidly. This process seems to have intensified after 1975, coinciding with the introduction of the first micro-computer based NC machine tools in 1974. But, as explained in Chapter 2, profound differences in international competitiveness between various machine tool types are expected. Specifically, the U.S. machine tool industry can be expected to be competitive in the field of mass production machinery, since it has excelled in this field because of the emphasis on high-volume production technologies in the U.S.

Comparable trade data at the machine level are not available for the U.S. after the mid-70s because of the changes in trade classification. Thus, data for only the period of 1980-1986 have been used in this section. Figures 4.17-4.20 display net export ratios for those machine tools that are associated with four manufacturing systems found by factor analysis.[10] For the purpose of comparison, the net export ratio of the metalcutting machine tool total is also shown in each figure.

As expected, the U.S. machine tool industry is relatively more competitive in the production of mass production equipment. All of those machine tools that are identified with transfer lines (factor TLINE) have net export ratios higher than that of total metalcutting machine tools in 1985 and

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[10] For data sources and machine tool definitions, see Tables A.1 and A.2.

1986. In other years, only mass-milling (MM) machines have a consistently lower net export ratio. The same is also true for factor SPEC that represents special systems. All but NC lathes in this group have net export ratios higher than the total in the period of 1980-1986. For the other two manufacturing systems, the competitive position is opposite of that of mass production machinery. In the early-80s, all but NC drilling machines in the FMS group had lower net export ratios. The relative position of the machine tools in this group have been improved to some extent after 1983. In the case of manufacturing cells (CELL), all machine tools have lower net export ratios than total in 1985 and 1986.

Table 4.4 Mean values and 'confidence intervals' of net export ratios for manufacturing systems

	Manufacturing Systems				
	Total	TLINE	SPEC	FMS	CELL
Mean	-.73	-.43	-.52	-.66	-.85
Mean + std. dev.		-.24	-.21	-.45	-.80
Mean - std. dev.		-.62	-.83	-.88	-.90

Notes: Mean value is the arithmetic mean of net export ratios of those machine tools shown in Figures 4.17-4.20 for each group.

In Table 4.4, the arithmetic means and 'confidence intervals' (mean +/- standard deviation range) for each group is given for 1986 to obtain a broad idea of the differences between the groups.

In 1986 (and in 1985, too), these groups are ranked according to the mean net export ratios as TLINE > SPEC > FMS > CELL. (Recall that, incidentally, this is the same order as the production volume for each manufacturing system as interpreted in Section 3.2.) Moreover, the net export ratio for total metalcutting machine tools total is lower than the 'confidence interval' of TLINE and higher than that of CELL. Although these inferences are not statistically rigorous, they may, nevertheless, be used to argue that the U.S. machine tool industry has a relatively better competitive position in the manufacturing of mass production machinery as shown in the higher values of net export ratio for those machine tools that are correlated with transfer lines and special systems, and the lower values for those machine tools that are correlated with flexible manufacturing systems and manufacturing cells (see Figures 4.17-4.20 for individual machine tools and Table 4.4 for group means).

The U.S. mass production machinery producers have been in a relatively better position throughout the period under consideration. But as shown in Figures 4.17 and 4.18, they lost their competitiveness to a large extent in 1984 and 1985, and there is not any indication that they will improve their competitive position in the near future. This 'lagged' decline in the segment of mass production machinery may be partially explained by intra-industry external economies and interdependencies. For example, the networks of small subcontractor firms who supply specialized parts to machine tool producers have been weakened by the decline of domestic FMS and cell producers. This, in turn, may have a negative effect on mass production machinery producers. The examples of these types of intra-industry external economies and interdependencies can be easily expanded.

4.4. Conclusions

In this chapter, recent changes in metalworking technologies and the reaction of the U.S. machine tool industry to these changes are analyzed. It is found that the development of NC machine tools and flexible automation technologies form the core of recent changes in metalworking. The systems based on flexible technologies have been increasing their share in the engineering industries by replacing conventional machine tools and, to some extent, mass production machinery. It seems that more integrated mass production machines, e.g., station-type machines, have resisted this trend in the U.S. Although, in the future, better economic conditions may increase the relative demand for mass production machinery, flexible automation technologies are the determinant factor for competitiveness for the time being.

The U.S. machine tool industry has lost its international competitiveness very rapidly after the mid-1970s. There are significant differences in the competitiveness of various technologies. The U.S. mass production machinery producers (TLINE and SPEC systems) have been more successful than others, presumably because of the long history of machine tool development linked with the ‘American System’ of manufacturing and mass production in the U.S. Although their position has not declined much in comparison with other types of machine tools, the data presented here indicate that mass production machinery producers have lost considerable competitiveness in the mid-80s.

CHAPTER 5

THE INTERRELATIONSHIPS BETWEEN MACHINE TOOL USERS AND PRODUCERS

5.1. Introduction

The interrelations between machine tool users and producers are explored in this chapter. More specifically, the focus is on the inertia in the relationships between machine tool producers and users, and the implications of a weakening domestic machine tool industry on the international competitiveness of the domestic engineering industries. As discussed in the preceding chapter, machine tool technology has been developing toward numerical control (and, hence, flexible automation) after the mid-1970s, but U.S. machine tool producers have not been successful in capturing market shares in the manufacturing of NC machine tools, presumably because of their emphasis on mass production equipment for a long time. Recently U.S. machine tool producers have experienced significant losses in the segments of mass production machinery, too. This lack of competitiveness of the U.S. machine tool producers would not be a serious problem for domestic machine tool users if they were capable of adopting new connections with technologically superior (foreign) producers instantaneously and without heavy costs involved during the adjustment period. But there may be some factors that are detrimental for establishing new user/producer relationships. In other words, there may be some factors that explain why machine tool users tend to employ machine tools from their 'old' suppliers even though they may be technologically inferior. Moreover, producers tend to develop technologies relatively close to their technological positions, which are largely determined by their previous production histories. Thus, those countries that were largely supplied by their respective domestic machine tool industry may experience a certain delay in the adoption of new metalworking technologies in those new technologies that are not relatively close to the domestic machine tool industry's technological capabilities. This delay may also cause a *temporary* loss of competitiveness of domestic machine tool user industries. The duration of this delay is determined by the time spent to form new relationships between domestic users and foreign suppliers and/or the imitation of those technologies by domestic producers. This chapter studies the experience of the US engineering industries in recent years from this perspective.

5.2. The Continuity of User/Producer Relationships

The question to be examined in this section is the inertia of machine tool users hindering the adoption of new vendors and suppliers, i.e., the tendency for repeat sales in machine tools assuming a 'satisfactory' level of quality. There is some evidence to support this hypothesis. Jacobsson gives an example from the experience of one of the pioneers of CNC lathes in Japan. '[This] firm claims that in 1967-68 it sold 51 units to thirty-six customers. In 1982, twelve out of these thirty-six customers had a stock of over 20 units of this firms's CNC lathes.' (Jacobsson, 1986: 101) But unfortunately this type of information is not suitable for statistical analysis.

There is also some evidence at the aggregate level. Long-term economic relationships between different regions can establish relations between machine tool users in one region with producers in other regions, and these relationships between machine tool users and producers can continue for some time, even after previous economic/political relationships between regions are broken. For example, Sciberras and Payne (1985: 9) observe that 'principal export markets [of the U.K. machine tool industry] are the U.S. and the "old Empire" countries, especially South Africa, Canada, and Australia'.

This hypothesis on the inertia exhibited by machine tool users to adopt new suppliers can be indirectly tested by using aggregate data on machine tool trade. A method to test this hypothesis at the aggregate level is to compare the rate of foreign direct investment (DFI) and the machine tool export share for a country. It is suggested that U.S. machine tools are heavily oriented to the less developed countries compared to other developed machine tool producer countries (almost half of U.S. machine tool exports go to the less developed countries), and 'a significant part of these exports are tied to direct foreign investment by U.S. automobile and mechanical engineering firms' (OECD, 1983: 11-12). Thus, in its modified form, the hypothesis on the inertia in the relationships between machine tool users and producers states that DFI by Country A in the engineering industries of Country B may have a positive impact on the share of machine tool imports by Country B from Country A. This impact may be especially significant if Country A had a relatively low machine tool import penetration in its own market by foreign producers. This type of positive relationship may be expected because foreign-owned companies, following the tendency to purchase from the 'proved' producers (i.e., parent company's machine tool vendors), may prefer to import from their home country. 'Demonstration effects' on local firms may intensify the preferences for Country A's machine tools over those of the other countries. The U.S. data to test this hypothesis are particularly suitable because the U.S. had a relatively low machine tool import penetration ratio until the 1980s and it has a relatively large amount of outward-DFI in the engineering industries compared to other developed countries.

The hypothesis can be formalized in a linear regression form as follows.

[5.1] $MSR_i = a_0 + a_1EMP_i + a_2MAJR_i + a_3DIST_i + a_4GNP_i + e_i$,

where MSR_i is the share of machine tool imports from the U.S. by the i^{th} country, EMP_i the share of U.S.-affiliated companies in total employment in the i^{th} country's engineering industries, $MAJR_i$ the share of majority-owned U.S. affiliated companies in total employment of all (majority and minority hold) U.S. affiliated companies, $DIST_i$ the distance between the U.S. and i^{th} country (measured as the distance between capital cities), GNP_i the i^{th} country's gross national product per capita (in US dollars), and e_i the error term.

In the U.S. statistics, DFI is defined as 'ownership or control, directly or indirectly, by one U.S. person of 10 per cent or more of the voting securities of an incorporated foreign business enterprise or an equivalent interest in an unincorporated foreign business enterprise including a branch' (Vukmanic, Czinota and Ricks, 1985: 168). Since there may be some differences in investment decisions between minority and majority held companies, a variable, MAJR, is used to reflect these differences. The MAJR variable is equal to the share of majority-owned U.S. affiliated companies (i.e., those enterprises in which more than 50% of shares are held by U.S. citizens or firms) in the employment of all U.S. affiliated companies. The coefficient of the MAJR variable is expected to be positive if investment decisions in majority owned firms are less influenced by local conditions, and if those firms have closer relations with the U.S. machine tool producers.

Table 5.1 Variables used in Equations 5.1, 5.2, and 5.4

	All countries		Developed countries		Less developed countries	
Variables	mean	std.dev.	mean	std.dev	mean	std.dev
MSR82	19.45	18.18	17.78	18.76	21.42	17.26
MSR86	12.03	11.11	10.83	13.70	13.44	6.61
EMP82	11.59	9.23	11.90	9.50	11.23	8.85
EMP86	10.90	9.60	11.38	9.98	10.34	9.09
MAJR82	78.15	23.01	78.95	22.65	77.21	23.39
MAJR86	65.09	26.79	59.86	20.44	71.26	31.66
DIST	8.4	3.8	6.7	2.7	10.5	4.0
GNP82	5.7	4.2	8.7	3.3	2.2	1.7
GNP86	6.7	5.9	10.5	5.4	2.1	1.9
MUS77	9.31	8.87				
MUS82	9.82	13.27				
EMPUS77	.24	.30				
EMPUS82	.39	.34				
WXS77	6.15	8.40				
WXS82	6.37	7.63				

Notes: MSR is the share of machine tool imports from the U.S. by 24 countries (Canada, Belgium, Denmark, France, FRG, Ireland, Italy, Netherlands, the U.K., Spain, Switzerland, Japan, the Republic of South Africa, Argentina, Brazil, Chile, Peru, Venezuela, Hong Kong, India, Indonesia, Philippines, Singapore, and South Korea, 13 former countries are included in the 'developed country' group); EMP the share of U.S. affiliated companies in total employment of the host country's engineering industries; MAJR the share of majority-owned U.S. affiliated companies in total employment of all (majority and minority hold) U.S. affiliated companies; DIST the geographical distance between the capital cities (in thousands km); GNP *per capita* gross national product; MUS$_i$ the share of U.S. machine tool imports from i'th country; EMPUS the share foreign affiliated companies in total employment of the U.S. engineering industries; WXS the share of foreign countries in world machine tool exports. Countries for MUS, EMPUS, and WXS variables are Canada, France, FRG, Netherlands, the U.K., Switzerland, Japan, 'Australia-New Zealand-Republic of South Africa', 'Latin America', and 'other Asia and Pasific'. MSR is dependent variable for the pooled data. MSRTR is truncated version of MSR where outlier countries (Canada, Japan, and Philippines) are excluded, and LMSR is the logit transformation of MSR. Similarly, MUS77 and MUS82 are pooled to form MUS. MUSTR is truncated version of MUS where Japan (an outlier) is excluded. In all variables, suffix denotes year.

Sources: Employment of U.S. affiliated companies in 1982, BEA (1985), *U.S. Direct Investment Abroad: 1982 Benchmark Survey Data*; in 1986, BEA (1987), *U.S. Direct Investment Abroad. Operations of U.S. Parent Companies and Their Foreign Affiliates. Preliminary 1986 Estimates*. Employment of foreign affiliated companies in the U.S. engineering industries, BEA, *Foreign Direct Investment in the U.S.*, related issues. Total employment in the engineering industries, U.N., *Industrial Statistics Yearbook*, related years. Machine tool trade data, U.N., *Yearbook of International Trade Statistics*, related years, and Bureau of Census, *U.S. Exports*, Schedule E (FT 450) and *U.S. Imports* (FT 650), and *American Machinist*, related issues. Except Hong Kong, GNP and population data, IMF, *International Financial Statistics*; for Hong Kong, *The New Encyclopaedia Britannica* (15th

Table 5.1 Continued

Edition). Geographical distance data are calculated from the coordinate data obtained from *The Prentice Hall American World Atlas*.

For those countries whose 1986 data are not available, data for the most recent year (generally 1985) were used. Employment of the foreign-affiliated companies in the U.S. engineering industries are not available for all sectors because of the confidentiality requirements of the BEA. For those countries/country groups, EMPUS variable represents the share of employment only in those sectors of engineering industries whose data are published. For Hong Kong, GNP82 and GNP86 data are for 1980.

The relative level of economic development of the importer country, and its geographical distance from the U.S. are other variables that may affect the share of machine tool imports from the U.S. Almost all of the developed countries in our sample are in Europe. GNP and DIST variables are used as proxy to reflect the effects of both variables.

Equation 5.1 is tested for 1982 and 1986.[1] The hypothesis has two implications for these tests. First, the coefficients of the EMP variable in both tests should be positive if there is a continuity in the use of machine tools produced by the same (i.e., U.S.) producers. Second, a reduction in the coefficient of EMP, a_1, is expected from 1982 to 1986 due to the gradual adoption process by users. As can be seen in Figure 4.17, the U.S. machine tool industry has been losing competitiveness, starting in the mid-1970s. Thus, it may be expected that U.S.-affiliated engineering companies (and other local

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[1] 1982 is selected because it is the benchmark survey year for the U.S. outward-DFI, and 1986 is the most recent annual survey available.

companies) in foreign countries may have been changing their machine tool suppliers by forming new connections with foreign machine tool producers, thereby, reducing the (positive) effects of DFI on machine tool imports from the U.S.

The significance of the coefficient of EMP variable is tested by the t-statistic. The reduction in the coefficient of EMP from 1982 to 1986 is tested by pooling two data sets in the following way.

$$[5.2] \quad MSR \;=\; \begin{vmatrix} MSR82 \\ MSR86 \end{vmatrix} \;=\; a_{82} \begin{vmatrix} EMP82 \\ \mathbf{0} \end{vmatrix} \;+\; a_{86} \begin{vmatrix} \mathbf{0} \\ EMP86 \end{vmatrix} + X\beta$$

where MSR82 and MSR86 are n*1 vectors of dependent variables, EMP82 and EMP86 are n*1 vectors for the share of U.S.-affiliated companies in total engineering employment, and X is the 2n*k matrix of the remaining explanatory variables including the constant term, and **0** is an n*1 null vector. Let Z be a 2n*(k+2) matrix of all explanatory variables. Under the null hypothesis that $a_{82} = a_{86}$, the following statistic is asymptotically distributed as a normal variable with zero mean and unit variance (Fomby, Hill and Johnson, 1984: 64).

[5.3] $u = (\hat{a}_{82} - \hat{a}_{86}) \,/\, (\hat{\sigma}^2 b'(Z'Z)^{-1}b)^{1/2}$, where b is the vector of linear constraints, $b' = [1 \;\; -1]$, $\hat{a}_{82}$, $\hat{a}_{86}$, and $\hat{\sigma}$ are OLS estimates of a_{82}, a_{86}, and σ, respectively. When the u-statistic is greater than 1.645, $\hat{a}_{82}$ is greater than $\hat{a}_{86}$ at the 5% level of significance.

The variables used in these tests, their means and standard deviations are shown in Table 5.1 along with the data sources. The average share of machine tool imports from the U.S. (MSR) by the less developed countries is slightly higher than that by the developed countries. From 1982 to 1986, the average MSR declined for both groups. This is a direct consequence of the declining share of the U.S. producers in total world machine tool exports. There is also a decline in the ratio of majority-owned U.S. affiliated companies in total DFI (MAJR), especially in the developed countries.

Table 5.2 Regression estimates of Equation 5.1

	Dependent variables					
Variables	MSR82	MSR82	MSRTR82	MSR86	MSR86	MSRTR86
EMP	1.65^{**}	1.55^{**}	1.29^{**}	$.89^{**}$	$.89^{**}$	$.47^{**}$
	(5.37)	(5.95)	(5.59)	(4.24)	(5.67)	(3.68)
MAJR	-.04		.04	.03		$.10^{**}$
	(-.36)		(.57)	(.38)		(2.42)
DIST	.40		-.48	.11		-.39
	(.48)		(-.86)	(.22)		(-1.19)
GNP	-.32		$-.90^{*}$	.02		$-.61^{**}$
	(-.45)		(-1.84)	(.07)		(-3.29)
R^2	63.8	61.7	72.4	60.0	59.3	72.1
Adj.R^2	56.1	60.0	65.5	51.5	57.5	65.1

Table 5.3 Regression estimates of Equation 5.2[2]

	Dependent variables		
Variables	MSR	MSRTR	MSR
EMP82	1.66**	1.30**	1.52**
	(6.78)	(7.44)	(8.64)
EMP86	.87**	.46**	.91**
	(3.36)	(2.56)	(5.14)
MAJR82	-.03	.05	
	(-.40)	(.83)	
MAJR86	.02	.10	
	(.27)	(1.63)	
DIST82	.47	-.45	
	(.81)	(-1.18)	
DIST86	.06	-.42	
	(.09)	(-.96)	
GNP82	-.28	-.88**	
	(-.51)	(-2.42)	
GNP86	-.002	-.62**	
	(-.01)	(-2.41)	
R^2	64.8	74.2	63.3
Adj.R^2	57.6	67.9	61.6
u-statistic	2.21**	3.35**	2.44**

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[2] There is, of course, no change in the DIST variable from 1982 to 1986. Since the effects of geographical distance mat change due to technological developments in transportation and communications, this variable is used with a slope dummy to reflect the effects of these changes. Accordingly, two coefficients of this variable, DIST82 and DIST86 were reported in this table.

Figure 5.1 Plots of MSR vs. EMP, 1982

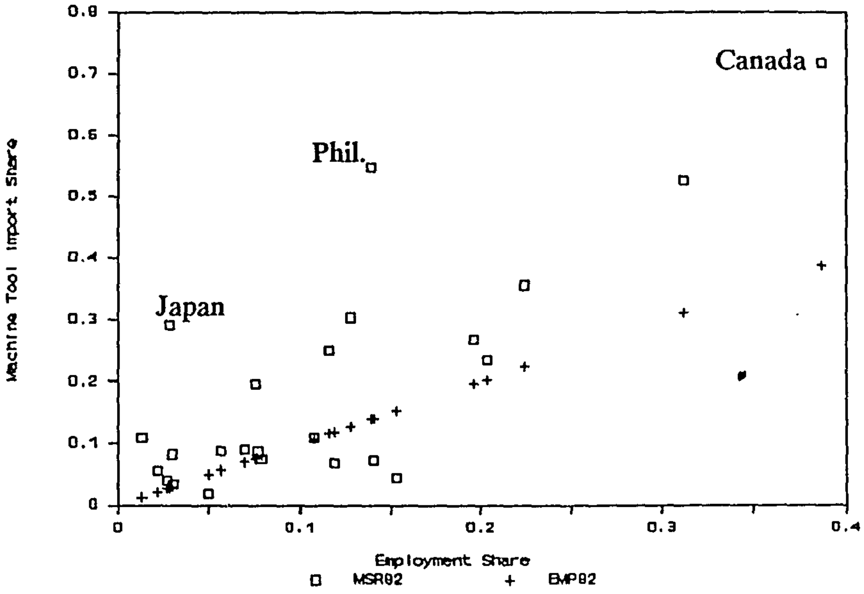
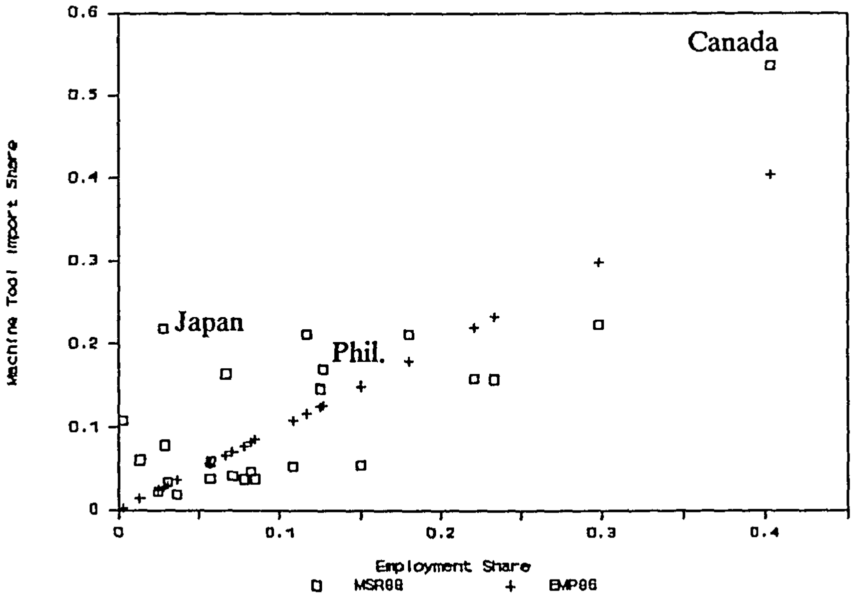


Figure 5.2 Plots of MSR vs. EMP, 1986



The OLS estimates of Equations 5.1 and 5.2 are shown in Tables 5.2 and 5.3. The coefficient of the MAJR variable has both positive and negative signs and its standard error is very high in almost all the estimations. Its coefficient is significant only in two cases. In both of these cases, it has a positive coefficient as expected. The coefficient of the DIST variable is not significant in any estimations. This means that geographical proximity does not have any notable impact on the imports from the U.S. The coefficient of the GNP variable becomes negatively significant in same cases indicating the difficulties of the U.S. machine tool producers to secure market shares in the developed countries.

The coefficient of the EMP variable is positive and statistically significant in all estimates. These results give support for the inertia hypothesis. Moreover, the u-statistic that is used to test the decline in the coefficient of EMP shows that there is a statistically significant decline from 1982 to 1986 (see Table 5.3). During this period, the share of the U.S. in total world machine tool exports declined from 6.30% to 4.41%. The decline in the coefficient of EMP variable may also reflect this overall decline in the export share of the U.S.

Observations on Canada, Japan, and the Philippines seem to be outliers in this sample (see also Figures 5.1 and 5.2). Canada has very high MSR and EMP values, whereas MSR values for Japan and the Philippines are very high compared to their EMP values.[3] Therefore, OLS estimates were found by excluding those countries (Table 5.3, dependent variable MSRTR). As expected, the value of estimated coefficients of the EMP variable are lower in these estimations.

This hypothesis can also be tested by examining the relation between the DFI in the U.S. and the import share of foreign countries. In this case, the linear model can be written as follows.

[5.4] $MUS_i = a_0 + a_1 EMPUS_i + a_2 WXS_i + e_i$, where MUS_i is the share of i^{th} country in the U.S. machine tool imports, $EMPUS_i$ the share of companies held by the i^{th} country in total employment of the U.S. engineering industries, WXS_i the share of foreign countries in total world machine tool exports, and e_i the error term. The DFI in the U.S. is proportionally much lower than outward-DFI, and concentrated to a few countries. DFI data on only 6 countries and 3 country groups could be obtained for 1977 and 1982 because of the confidentiality requirements of BEA. Moreover, data on these countries are also deficient relative to outward-DFI data since data on EMPUS variable could be found for some (different) sectors of the U.S.

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3. Geographical and economical proximity of Canada to the U.S. may explain its high MSR and EMP values. Philippines was a colony of the U.S., and its close relationships with the U.S. may continue up to now. Japan has an exceptionally low import penetration ratio (less than 10%) during this period. Japan's machine tool imports may be conditioned by its efforts for 'reverse engineering' that tend to increase the share of machine tool imports from the U.S. (high MSR value). Moreover, the legal and cultural difficulties of foreign direct investment in Japan may cause a low level of EMP value.

engineering industries for some countries/country groups. Basic statistics on variables, and data sources are shown in Table 5.1.

Table 5.4 Estimates of Equation 5.4

	Dependent variables					
Variables	MUS77	MUSTR77	MUS82	MUSTR82	MUS	MUSTR
DUMCTR	.63 (.09)	3.29 (1.23)	-2.99 (-.21)	5.00 (1.44)	-1.63 (-.23)	4.13** (2.09)
EMPUS77	3.42 (.36)	8.60** (2.45)			1.69 (.15)	8.62** (2.76)
EMPUS82			-9.52 (-.55)	3.96 (.90)	-7.46 (-.69)	3.83 (1.25)
WXS77	.80** (2.46)	.79** (6.67)			.75** (1.86)	.78** (7.14)
WXS82			1.17* (1.76)	.55** (3.20)	1.20** (2.53)	.56** (3.89)
R^2	60.1	78.5	40.4	78.8	46.0	87.8
Adj.R^2	40.2	67.8	10.6	68.2	-21.5	72.6

The estimates of Equation 5.4 for 1977 and 1982 are shown in Table 5.4. As in Equation 5.4, data for both years are pooled to test changes in this period. In all estimates shown in Table 5.4, the coefficient of WXS variable is positive and statistically significant. The coefficient of MUS variable becomes significant (and positive) when Japan is excluded from the sample. As in the estimates of Equations 5.1 and 5.2, Japans seems to be an outlier in this sample, too. Japan's share in machine tool imports of the U.S. is much higher than the share of Japanese affiliated companies in total employment of the U.S. engineering industries.[4] The ratios of the mean MUS to the mean EMPUS variables are 39.1 and 25.1 in 1977 and 1982, respectively, whereas same ratios for Japan are 244 and 136.

Changes in the coefficients of EMPUS and WXS variables are tested by using the u-statistic of Equation 5.3. It is equal to 1.10 for EMPUS and 1.27 for WXS. Both statistics are not significant at the 10% level, i.e., the null hypothesis that there is not any change in these coefficients from 1977 to 1982 can not be rejected. Note that the main hypothesis on the tendency for repeat sales in machine tools does not require any change in the coefficient of EMPUS variable.

5.3. The Effects of Weakening U.S. Machine Tool Industry

Three arguments that compose the main hypothesis developed in Chapter 2 have been confirmed to be valid in the preceding section: (i) Recent changes in machine tool technology emphasize flexible automation whose principal component is NC technology; (ii) the U.S. machine tool industry is less competitive in this field than in mass production machinery; and (iii) there is an inertia in the 'decision rules' of machine tool users in the adoption of relations with new machine tool producers. In this section, the logical

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[4] Japanese leadership in the field of NC machine tools (especially in the production of NC lathes and NC machining centers) may be responsible for the relatively high share of Japanese in the machine tool imports of the U.S.

extension of these arguments, the hypothesis on the possible effects of the declining U.S. machine tool industry on the international competitiveness of domestic user industries, is examined. This hypothesis states that the decline of the U.S. machine tool industry after the late-1970s may lead to a temporary decline in the international competitiveness of the US engineering industries since the user industries have historically tended to use domestically produced machine tools and they have lagged behind their competitors in adopting new metalworking technologies developed in other countries and, especially, in Japan. If this hypothesis is true, it may be assumed that this decline in competitiveness may be overcome and reversed by the adoption of new technologies through new producer/user relationships.

5.3.1. A regression model of international competitiveness

Although there has been a general deterioration in the competitiveness of the U.S. machine tool industry (i.e., the international competitiveness of the U.S. machine tool industry has been declining in almost all types of machine tools), there are significant differences among various machine tool types. For example, the decrease in the net export ratio of machining centers is very large, whereas the ratios for gear-cutting and grinding machines are still relatively high. Each industry has a different composition of machine tool stock and investment because of the differences in their manufacturing characteristics. Therefore, the effects of the deterioration in the domestic machine tool industry on user industries may be uneven: in some industries, it may be high, in some others, it may be low depending on the level of worsening competitiveness in the domestic production of various types of machine tools and the intensity of their use by each industry. By using these variations, it may be possible to test the above-mentioned hypothesis as follows.

Indexes for the trade performance, $MTTP_j$, (defined as net export ratio) are calculated for 22 types of machine tools. These groups are almost the same as those used in the factor analysis in Chapter 3. Then these indices were multiplied by the share of each machine tool in the total industry stock to find out the total effects of deterioration in domestic machine tool production on user industries. That is,

[5.5] $EFFMT_i = \Sigma_{j=1}^{n} MTTP_j \cdot MS_{ij}$, where $EFFMT_i$ is a proxy for the effects of deterioration in domestic machine tool production on the i^{th} industry, $MTTP_j$ the index for the trade performance of the j^{th} machine tool type, and MS_{ij} the share of the j^{th} machine tool type in the total stock of the i^{th} industry. This index, EFFMT is introduced into the regression Equation 5.6 to verify its effect on the trade performance of the U.S. engineering industries.[5]

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[5] The MS variable is available in machine units while the MTTP variable is available in both unit and value terms. It was found that there is not any significant change in EFFMT variable when unit or value MTTP is used. Since value MTTP is a better representative of international competitiveness as used in Figures 4.17-4.20, EFFMT calculated from value MTTP is used in this section.

The method to be used to test this hypothesis is linear regression analysis. The model can be represented in the following equation.

[5.6] $TP_i = a_0 + a_1 EFFMT_i + \ldots + e_i$, where TP_i is the trade performance of the i^{th} industry (at the SIC 3-digit level), EFFMT is a proxy for the effects of weakening domestic machine tool industry on the i^{th} engineering industry, and e_i the error term.

There are various measures that can be used to measure trade performance. The most widely used variables are the following.

[5.7] Net export ratio, $NXR_i = (X_i - M_i)/(X_i + M_i)$, where X denotes exports, M imports, and subscript i for i^{th} industry.

[5.8] Export-import ratio, $XMR_i = X_i/M_i$.

[5.9] Trade gap ratio, $TGR_i = (X_i - M_i)/V_i$, where V_i is either home demand $(Q_i + M_i - X_i)$, or total supply $(Q_i + M_i)$, and Q_i domestic production.

[5.10] 'Revealed comparative advantage', $RCA_i = (X_i/X_m)/(X_i^w/X_m^w)$, where subscript m stands for total manufacturing and superscript w for total world.

The last variable, RCA, would have been the best variable but it would have been practically very difficult to find comparable trade data at the SIC 3-digit level. The third variable, TGR, reflects the effects of tradability of products. For example, a country that has very low competitiveness in a product may have relatively small trade gap ratio if that product is not tradable (for a discussion of the advantages and disadvantages of various variables, see Ohlsson, 1980: 16-22). Thus, NXR and logarithmic form of XMR are used as measures of trade performance, TP, in Equation 5.6.

The NXR variable is, by definition, bounded by -1 and +1. Under this condition, OLS estimates may be inefficient since this prior information is not used in the estimation process. To secure more efficient estimates, the NXR variable can be transformed by using, for example, a logit transformation. For this purpose, NXR is first transformed linearly to vary between 0 and 1 as follows.

$NXR^{+} = (NXR+1)/2$. Then, the logit transformation is applied to NXR^{+}, as

$LNXR = ln[NXR^{+}/(1-NXR^{+})]$. This logit transformation of NXR is also used in our estimations. (Note that the LNXR variable is exactly equal to $ln(X/M)$. That is, the logarithmic form of the export-import ratio is used in estimations.)

Some other variables can also affect trade performance. Those variables should be also included in this equation since estimates of the coefficient of EFFMT can be biased otherwise. The following variables are included in Equation 5.6. (For definitions of variables and data sources, see Table 5.5.)

TLINE, SPEC, FMS, and CELL. These variables are factor scores found by factor analysis from machine tool stock data and represent 'transfer lines', 'special systems', 'flexible manufacturing systems', and 'manufacturing cells', respectively. Flexible automation technologies have become an important factor enhancing the international competitiveness of engineering firms (for a detailed analysis, see Edquist and Jacobsson, 1988: 91-112). Moreover, it is also found that the use of flexible technology makes a positive contribution to the international competitiveness of the U.S. engineering industries (Carlsson, 1988). Thus, the coefficient of the FMS variable is expected to be positive. The coefficients of other variables (especially those of intermediate technologies, SPEC and CELL) are ambiguous. The coefficient of TLINE (and SPEC) may be negative depending on the extent of shifts away from mass production technologies.

SCI, CAP, and ENER. These variables are used to represent human capital intensity, (physical) capital intensity, and energy-related natural resource intensity, respectively, to reflect the effects of factor intensities on trade performance. SCI is the share of scientists in total employment, CAP the value of depreciable assets (building, machinery, and equipment) per employee, and ENER the share of energy costs in total output. Since more than two factors and products (industries) are used, there is no clear-cut relation between relative factor endowments and trade flows. As Maskus (1983: 12) says, 'the signs of the regression coefficients cannot be interpreted as strict measures of the [factor] endowments'. Judging from the previous literature, the coefficient of SCI is expected to be positive whereas the coefficients of CAP and ENER are uncertain.[6]

AVERS. This variable is equal to the average size of establishments in each industry (average number of employees per establishment). It may reflect the scale effects other than technology because the effects of manufacturing technologies are directly estimated by TLINE, SPEC, FMS, and CELL. Since it is generally supposed that the U.S. has a comparative advantage in large-scale production, this variable may be expected to be positive (or, at least, nonnegative).

DFI. This variable represents the relative DFI position of the U.S. in each industry; it is used to capture the effects of some other factors that are not included in the above-mentioned variables. Although the relationship between DFI and international trade is not apparent, Dunning (1981), based on the 'eclectic theory', argues that both ownership and internalization advantages of the investor/exporter are necessary conditions for both DFI and international trade. The choice between DFI and trade is based on the third condition, (foreign) location advantages (immobile resources, transportation costs, industry-specific tariff and non-tariff barriers, etc.). Moreover, another important factor that affects the choice between DFI and trade is the strategic

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[6] Our sample consists of only a subset of manufacturing industries, i.e., the engineering industries. Therefore, if any one of the variables discussed here is found not to be significantly different from zero, this result means that the variable does not explain the variation in the trade performance variable in the engineering industries. The same variable, of course, may be significant when it is used in a sample that includes all manufacturing industries.

choices and market positions of competitive firms in that industry. The coefficient of the DFI variable depends on whether DFI complements or substitutes for international trade in the engineering industries. For example, if DFI is a result of tariff barriers, it may substitute for trade. On the other hand, if it occurs mainly due to firms' strategic choices to improve their competitive positions in foreign markets against other countries, it may be complementary to trade. Note that, in both cases, the investor/exporter firm should have the same advantages (ownership and internalization) to carry out either DFI or trade.

Lipsey and Weiss (1981) studied the relationship between DFI by U.S. firms and the U.S. export shares in 14 manufacturing industries (generally at the SIC 2-digit level). They found that the level of economic activity of U.S. affiliates is positively related to U.S. exports to host countries, and also negatively correlated with exports by 13 other competitive developed countries (mostly E.E.C. countries) in the less developed countries. This relationship is somewhat higher among metals and machinery groups which corresponds to our sample.[7] Thus, a positive coefficient for the DFI variable may be expected.

The complete model to test the effects of a declining domestic machine tool industry on user industries is as follows.

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[7] Lipsey and Weiss (1981: 494) interprets these findings as a support 'to the idea that direct investment abroad is a method by which oligopolistic firms compete abroad for shares in host country markets'.

[5.11] $NXR_i = a_0 + a_1EFFMT_i + a_2TLINE_i + a_3SPEC_i + a_4FMS_i + a_5CELL_i + a_6SCI_i + a_7CAP_i + a_8ENER_i + a_9AVERS_i + a_{10}DFI_i + e_i$

[5.12] $LNXR_i = a_0 + a_1EFFMT_i + a_2TLINE_i + a_3SPEC_i + a_4FMS_i + a_5CELL_i + a_6SCI_i + a_7CAP_i + a_8ENER_i + a_9AVERS_i + a_{10}DFI_i + e_i$

These equations are estimated for 1979 and 1984 trade data to examine the changes in recent years. If a reduction in the coefficient of EFFMT is found from 1979 to 1984, it may mean that the negative effects of a declining machine tool industry may have decreased due to the adoption of new technologies via new (foreign) producer/user relationships. Since two series of the EFFMT variable are required for 1979 and 1984, the MTTP index is calculated for two periods, by 1980-82 and 1984-86 averages. (Average values for the MTTP index are used to eliminate the effects of annual fluctuations in the net export ratios of each machine tool type.) The MS variable (in Equation 5.5) is for 1983 because the machine tool stock data are available only for this year. Since changes in the MS variable are relatively slow, the use of same year for MS may not create any serious problem.

In the estimation of the above-mentioned models, one may suspect the problem of heteroscedasticity, because the dependent variable for each industry is an average value for products that form the 'industry'. The basic model should be valid at the product level, and it can be rewritten as follows.

[5.13] $NXR_{ij} = a_0 + a_1EFFMT_{ij} + ... + e_{ij}$, where i and j denote 'industry', and product, respectively. e_{ij} is assumed to be identically and independently distributed with zero mean and finite variance, σ^2.

The NXR_i variable used in Equation 5.11 is basically a weighted average value over j as follows.

$NXR_i = \Sigma^{ki}_{j=1} w_{ij}NXR_{ij}$, where $w_{ij} = (X_{ij} + M_{ij})/(X_i + M_i)$, $X_i = \Sigma^{ki}_{j=1} X_{ij}$, $M_i = \Sigma^{ki}_{j=1} M_{ij}$, and k_i the number of products that constitute the i^{th} industry. Similarly, other variables are also weighted averages of product variables. Thus, Equation 5.13 can be written as follows.

[5.14] $NXR_i = a_0 + a_1(EFFMT_i + \Sigma^{ki}_{j=1} (w_{ij} - v_{ij})EFFMT_{ij}) + ... + e^*_i$, where v_{ij} are weights used to find $EFFMT_i$ from $EFFMT_{ij}$ ($EFFMT_i = \Sigma^{ki}_{j=1}v_{ij}EFFMT_{ij}$), and $e^*_i = \Sigma^{ki}_{j=1}w_{ij}e_{ij}$. Other weights are defined similarly.

Apparently, e^*_i is heteroscedastic because

$E(e^{*2}_i) = E(\Sigma^{ki}_{j=1}w_{ij}e_{ij})^2$, and assuming e_{ij}s are independent of w_{ij}s,

[5.15] $E(e^{*2}_i) = \Sigma^{ki}_{j=1}E(w_{ij}\ e_{ij})^2 = \sigma^2\Sigma^{ki}_{j=1}(w_{ij})^2 = W_i\sigma^2$, where $W_i = \Sigma^{ki}_{j=1}(w_{ij})^2$.

The estimates of coefficients when aggregate data at the industry level are used may be different from those that are obtained when data at the product level are used. These two estimates will be same when i) all the products within each industry have exactly the same dependent variables (i.e., $EFFMT_{ij} = EFFMT_i$, $j = 1,...,k_i$, $i = 1,...,N$); ii) the differences between the weights of the dependent variable and each explanatory variable are equal to zero for all products (e.g., $w_{ij} = v_{ij}$ for all i and j), and iii) weights and dependent variables are nonstochastic. Ohlsson (1980: 78-95) found that estimates based on data at the 'industry' level are not sensitive to the varying degree of heterogeneity and differences in variable weights --conditions (i) and (ii)-- in the engineering industries of Sweden. (Recall that the first condition is satisfied when the products of an industry are closely related as assumed in the concept of 'industry'.) Thus, we assume that the estimates of coefficients at the industry level are the same as those at the product level. On the other hand, the problem of heteroscedasticity should be explored here since there is not any a priori assumption suggesting homoscedastic variance in Equation 5.14.

The variance of the error term for each observation (i.e., for each industry) is proportional to the sum of squares of weights (W_i) used in that industry to find NXR_i. Since the weights 'used' are not observable, some proxy variables can be used to test the existence of heteroscedasticity. Three variables are chosen for this purpose.

i) When the products in each 'product' are assumed to be properly defined at the SIC 8-digit level, each 8-digit category in the trade classification can be used to approximate unobservable weights. In this case, the variable is calculated as

$$W_i = WEIGHT_i = \Sigma^{ki}_{j=1}[X_j/(X_i+M_i)]^2 + \Sigma^{ki}_{j=1}[M_j/(X_i+M_i)]^2 \quad ,$$

where j denotes the 'product' at the SIC 8-digit level, and i denotes the 'industry' at the SIC 3-digit level.

ii) If each product in an industry has equal value of total trade, then $W_i = DIGIT_i = (1/k_i)^2$, where k_i is the number of products in each industry. Moreover, if it is assumed that each 'product' is represented by an SIC 8-digit category, the number of 8-digit categories in each SIC 3-digit group can be used to test heteroscedasticity.

iii) The number of products (k_i), and the sum of squares of weights (W_i) can be assumed to be proportional to total trade in each industry. In this case, total trade (TT_i) can be used for test purposes.

The WEIGHT and DIGIT variables are calculated for 1984, and the TT variable is found for both 1979 and 1984 data. These variables are used to test heteroscedasticity by using Breusch-Pagan and Goldfeld-Quandt tests. Among 12 tests (2 years * 3 proxy variables for heteroscedastic disturbances * 2 test methods), only the 1984 model shows the existence of heteroscedasticity at the 5% level of significance when the Goldfeld-Quandt test based on the TT variable is used. Therefore, it is assumed that heteroscedasticity is not a serious problem. These models are also estimated by a method suggested by White (1980) ('robustse' option in the 'OLSQ' command of the TSP package). The estimator of the variance-covariance matrix under this method is consistent even when the disturbances are not homoscedastic. Note that the result of variance estimates are very close to those of the OLS procedure as implied by the results of heteroscedasticity tests (see, Tables 5.7 and 5.9).[8]

5.3.2. Results of regression estimates

The variables used in the estimation of Equations 5.11 and 5.12 and the data sources are shown in Table 5.5. The mean values of the variables reflect general conditions of the U.S. engineering industries. An important decline in the mean value of the net export ratio (NXR) from 17% to -1% is shown in this table. That is, the U.S. engineering industries have experienced a deterioration in their international competitiveness during this period.

The decline in the EFFMT variable from -.24 to -.31 is a result of continuing decline in the U.S. machine tool industry. In both years, all engineering industries had negative EFFMT value which indicates that all of them are negatively affected by the competitive position of the U.S. machine tool industry.

The DFI variable that is constructed in a similar way as the NXR variable has become lower in 1985 than that in 1980, i.e., inward-DFI became higher than outward-DFI on average in the early 1980s. All factor intensity variables (CAP, ENER, and SCI) have increased their average values.

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[8] If the distribution of W_i variable in Equation 4.15 is relatively homogenous, heteroscedasticity may not be a serious problem. The results of heteroscedasticity tests may denote this condition.

Table 5.5 Variables used to test Equations 5.11 and 5.12

Variables	Mean	Standard deviation
NXR79	.17	.42
NXR84	-.01	.43
LNXR79	.41	1.04
LNXR84	-.03	1.05
EFFMT79	-.24	.06
EFFMT84	-.31	.07
AVERS79	182.43	276.98
AVERS84	139.45	227.67
ENER79	.01	.01
ENER84	.02	.01
CAP79	16.38	6.88
CAP84	31.87	15.28
DFI80	.52	.36
DFI85	.42	.36
SCI80	.47	.44
SCI83	.61	.48
TLINE	-.10	.78
CELL	-.04	1.01
FMS	.6	1.01
SPEC	.01	1.03

Notes: The sample consists of 40 engineering industries mainly at the SIC 3-digit level. All but three industries used in factor analysis are used in the estimation of Equations 5.11 and 5.12. The industries excluded from the sample are SIC 347 (produces non-tradable services), SIC 359, and SIC 376 industries whose comparable trade data are not available.

The variables are defined as follows. NXR: the net export ratio (X-M)/(X+M); LNXR: the logit transformation of NXR which is also equivalent to *ln*(X/M); EFFMT: proxy variable for the effects of decline in domestic machine tool industry on user industries as defined inEquation 5.5; AVERS: average number of employees per establishment; CAP: the value of depreciable assets per employee; SCI: the share of scientists in total employment; ENER: the share of energy costs in total output; DFI: the net direct foreign investment ratio, DFI = (ODFI-IDFI)/(ODFI+IDFI), where ODFI is outward-DFI position and IDFI inward-DFI position. TLINE, CELL, FMS, and CELL are factors representing manufacturing systems (Table A.3).

Sources: Trade data for 1979: DoC (1986), *U.S. Commodity Exports and Imports as Related to Output*; for 1984: aggregated from SIC 8-digit level from DoC (1986), *U.S. Exports* (FT 610), and DoC (1986), *U.S. Imports* (FT210); Number of establishments and employees used to find AVERS variable: Bureau of the Census, *County Business Patterns*, related years; The share of scientists in total employment: NSF (1983), *Scientists, Engineers, and Technicians in Manufacturing and Nonmanufacturing Industries: 1980-1981*, and NSF (1985), *Scientists, Engineers, and Technicians in Manufacturing Industries: 1983*; DFI position: BEA, *Survey of Current Business*, related issues (Because of the confidentality requirements, DFI position data on some industries are not available for 1980 and/or 1985. In those cases, data for the closest year were used.); Machine tool trade data, see Table A.2; All other data were obtained from Bureau of the Census, *Annual Survey of Manufacturers*, related years.

Table 5.6 Correlation matrix for variables

	NXR	LNXR	EFF.	TL.	CELL	FMS	SPEC	ENER	CAP	SCI	AV.	DFI
1979 Data												
NXR79	1.00											
LNXR79	.99	1.00										
EFFMT79	-.08	-.06	1.00									
TLINE	-.15	-.14	-.13	1.00								
CELL	.04	.02	-.47	-.10	1.00							
FMS	.36	.35	-.58	.12	.03	1.00						
SPEC	-.03	-.03	.21	-.01	.01	-.00	1.00					
ENER79	.02	.02	.01	.03	-.23	.02	-.21	1.00				
CAP79	.03	.03	.19	.24	-.24	-.01	-.09	.20	1.00			
SCI80	.41	.42	-.35	-.06	.56	.14	.08	-.25	-.07	1.00		
AVERS79	.26	.33	.02	.07	.04	.05	.01	-.15	-.01	.51	1.00	
DFI80	.22	.22	.26	.07	-.16	-.21	.25	.12	.44	.12	-.01	1.00
1984 Data												
NXR84	1.00											
LNXR84	.99	1.00										
EFFMT84	-.10	-.11	1.00									
TLINE	-.08	-.07	-.25	1.00								
CELL	.06	.04	-.46	-.10	1.00							
FMS	.33	.34	-.54	.12	.03	1.00						
SPEC	.05	.04	.06	-.01	.01	-.00	1.00					
ENER84	.21	.22	.20	.01	-.29	.04	-.20	1.00				
CAP84	.11	.12	.05	.30	-.29	.20	.02	.39	1.00			
SCI83	.33	.33	-.50	.08	.49	.14	.15	-.33	.21	1.00		
AVERS84	.26	.25	-.11	.02	.08	.03	-.01	-.11	-.01	.41	1.00	
DFI85	.11	.15	.24	.05	-.13	-.27	.30	.13	.39	.11	-.08	1.00

The correlation matrix of all variables is shown in Table 5.6. The international competitiveness variables (NXR and LNXR) have positive and significant correlations with 'flexible manufacturing systems' (FMS), science intensity (SCI), and average establishment size (AVERS) in both years. The proxy variable for the effects of declining domestic machine tool industry on user industries (EFFMT) is negatively (but statistically insignificantly) correlated with NXR and LNXR. As expected, EFFMT is significantly negatively correlated with the CELL and FMS variables in both years. EFFMT is also significantly negatively correlated with the SCI variable . Furthermore, SIC is positively correlated with the CELL and FMS variables. These results may indicate that science-intensive industries need to utilize small batch production systems more than others.

The simple correlation coefficients, though they may be informative, do not explain the effects of one variable on others. To determine the simultaneous effects, the regression estimates of Equations 5.11 and 5.12 are found. The OLS estimates are depicted in Table 5.7. Since the estimated coefficients for the AVERS, TLINE, CELL, and SPEC variables are not statistically significantly different from zero at the 10% level in both equations, they are excluded from the model and new estimators are found for other variables (Table 5.8).

As explained in Section 5.3.1, heteroscedasticity may be expected even though our tests show that it may not be a serious problem. Therefore, heteroscedasticity-consistent estimates are also found by using White's method (see p.144 above). As shown in Table 5.9, heteroscedasticity-consistent estimates have higher t-statistics for almost all of the coefficients but the increases in t-statistics are not substantial, and there is not any significant change in the interpretation of regression results. This may be viewed as support for the results of the heteroscedasticity tests.

There are two time periods used in estimations of Equations 5.11 and 5.12. The error term for these years may be expected to be correlated. A seemingly unrelated equations model is used to estimate both equations simultaneously (Table 5.10). The results of the estimation are very close to those of the OLS estimates.

During the OLS estimation and heteroscedasticity tests, it was found that two industries may be outliers in the sample (namely, SIC 346A, metal forgings, and SIC 372A, complete aircraft industries)[9], and those industries that have very low total trade tend to have larger absolute error values. For these reasons, two different sets of estimations are carried out by excluding outliers (Table 5.11) and 6 low-trade industries (Table 5.12). The exclusion of these industries increase the fit of regression (R^2) and t-statistics of many variables.

Another set of estimates is found using the probit methods. It is contended in the trade literature that the determinants of international trade (e.g., comparative advantages) can explain only the direction, not the quantity, of trade. 'Trade should therefore be analyzed empirically using a statistical technique that is appropriate to a model in which the dependent variable is binary rather than continuous. Such a technique is probit [or logit] analysis which is based on a model in which the probability of the dependent variable

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[9] Outliers/influential observations are found by using Mahalanobis' and Cook's distance (Norusis, 1988: 211-213). These statistics for SIC 346A and 372A were much higher than those of other observations.

being of a particular sign is related to a list of explanatory variables' (Deardorff, 1984: 473). Although the magnitude of the dependent variable is important in our case, and, as Deardorff stated, 'it is hard to see that the theoretical basis for using these bivariate techniques is really any stronger than for OLS regression', probit estimates of Equation 5.11 are also found so as to compare the results of OLS and probit estimation (Table 5.13).[10] As can be seen in Tables 5.7 and 5.13, there is no major change in the interpretation of the results of probit and OLS estimations.

Finally, the data are pooled to find estimates of the coefficients of EFFMT79 and EFFMT84 together, as in Equation 5.2, and the u-statistic to test the decrease in the coefficient of EFFMT from 1979 to 1984 is calculated (Table 5.14). The t-statistics in this table are slightly higher than those of other estimates.

In all estimations, the coefficient of the EFFMT variable is positive and in most of the cases, it is statistically significant at the 10% level in a two-

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[10] Probit estimates are found by treating positive values of the dependent variable, NXR, as one and negative or zero values as zero. In the probit method, it is assumed that the dependent variable, y_i, which is 1 if the event occurs (in our case, if the industry has positive net exports), but zero otherwise, has the following probability function.

$$y_i = \begin{cases} 1 \text{ with probability } P_i \\ 0 \text{ with probability } 1\text{-}P_i \end{cases}$$

, where $P_i = F(x_i'ß)$, F( ) the cumulative normal distribution function, x_i the explanatory variables, and ß the coefficients of explanatory variables. ß can be estimated by maximum likelihood methods.

Two comments on the results of probit method are worth mentioning. First, the estimated coefficients do not show the magnitude of change in the probability function, P_i. The change in the probability function is also dependent on the steepness of the cumulative distribution function at $x_i'ß$. Second, the R^2 (or, in other words, pseudo-R^2) does not have the same meaning as in the case of OLS. Therefore, in Table 4.13, only the log of the likelihood function was tabulated.

tailed test. Recall that the hypothesis requires a positive coefficient, and a one-tailed test is appropriate to test this hypothesis. In other words, the coefficient of the EFFMT variable is statistically significant in almost all estimations at the 5% level under the null hypothesis. The coefficient of EFFMT is in the range of 2-3 suggesting that a simultaneous .1 point decrease in the net export ratio of *all* types of machine tools, other things being equal, leads to approximately .25 point decrease in the net export ratio of the U.S. engineering industries.

The coefficient of EFFMT79 is barely higher than that of EFFMT84, but the difference is not statistically significant as shown in the u-statistics of Table 5.14. On the basis of this result, we may conclude that the (negative) effects of depressed competitiveness of the U.S. machine tool industry on domestic engineering industries did not change during the early-80s. There may be two different explanations of this result: i) The adoption process of new connections with (foreign) producers may not be advanced enough even in 1984 to lessen these effects. ii) The proximity to technologically advanced machine tool producers may be an important factor for the international competitiveness of users at any time, i.e., the impact of demolishing domestic technological capabilities concentrated in the machine tool industry may be effective not only in the transitional periods, but permanently. This subject is explored in detail in the following chapter.

The estimates of the coefficients of other variables are generally in accordance with a priori expectations. Among manufacturing system variables, the FMS variable has a statistically significant positive coefficient in all estimations. It is one of the most significant variable in all models. The coefficients of high volume production systems, TLINE and SPEC, are not usually statistically significant, but their coefficients are negative in all cases where the absolute value of their t-statistics is higher than 1. In a few cases, they have statistically significant coefficients at the 10% level (see Tables 5.11, 5.12, and 5.13). The coefficient of CELL is not statistically significant in any model.

Among factor intensity variables, the SCI variable has consistently significant positive coefficients, whereas the coefficients of ENER and CAP are positive and negative, respectively, in all models, and they become statistically significant in many cases. Signs of SCI and CAP variables are consistent with the findings of Branson and Monoyious (1977).

The coefficient of the DFI variable is positive and statistically significant in almost all cases. This result is consistent with those of Lipsey and Weiss (1981) who found strong positive effects of DFI on the trade share of the U.S. engineering industries.

The coefficient of AVERS variable is not significant. This may be a result of the use of explicit technology variables to reflect the effects of various types of manufacturing systems (TLINE, SPEC, FMS, and CELL).

Other effects arising from large size may not be significant to explain the variances in the international competitiveness within the engineering industries.

Table 5.7 **Determinants of international competitiveness**
(OLS results)

Variables	Dependent variables NXR79	 LNXR79	 NXR84	 LNXR84
EFFMT	2.57*	6.42*	2.24*	5.17*
	(1.69)	(1.73)	(1.81)	(1.76)
AVERS	.00	.00	.00	.00
	(.09)	(.61)	(.40)	(.41)
CAP	-.01	-.02	-.01**	-.04**
	(-.86)	(.38)	(-2.28)	(-2.46)
DFI	.40*	1.01*	.27	.83*
	(1.81)	(1.87)	(1.30)	(1.71)
TLINE	-.08	-.20	.01	.02
	(-.96)	(-1.03)	(.08)	(.11)
CELL	-.00	-.01	-.04	-.12
	(-.05)	(-.06)	(-.54)	(-.65)
FMS	.25**	.62**	.25**	.64**
	(3.21)	(3.29)	(3.10)	(3.31)
SPEC	-.09	-.24	-.01	-.06
	(-1.49)	(-1.54)	(-.22)	(-.41)
ENER	4.68	11.15	24.30**	59.38**
	(.45)	(.44)	(2.77)	(2.85)
SCI	.42*	.94*	.66**	1.59**
	(1.91)	(1.76)	(2.92)	(2.98)
R^2	47.4	49.6	47.2	49.8
Adj.R^2	29.3	32.2	29.1	32.5

Table 5.8 Determinants of international competitiveness
(OLS results)

Variables	Dependent variables NXR79	LNXR79	NXR84	LNXR84
EFFMT	2.32*	6.41**	2.41**	5.57**
	(1.92)	(2.15)	(2.36)	(2.29)
CAP	-.01	(-.02)	-.01**	-.03**
	(-.76)	(-.76)	(-2.61)	(-2.74)
DFI	.29	.67	.24	.74*
	(1.43)	(1.37)	(1.31)	(1.70)
FMS	.22**	.58**	.25**	.64**
	(3.26)	(3.38)	(3.47)	(3.65)
ENER	8.70	21.72	24.51**	60.37**
	(.86)	(.87)	(3.07)	(3.17)
SCI	.43**	1.12**	.54**	1.52**
	(2.93)	(3.08)	(3.96)	(3.95)
R^2	41.1	42.4	46.0	48.1
Adj.R^2	30.4	31.9	36.2	38.7

Table 5.9 Determinants of international competitiveness (heteroscedasticity consistent results)

	Dependent variables			
Variables	NXR79	LNXR79	NXR84	LNXR84
EFFMT	2.57*	6.42*	2.24*	5.17*
	(1.85)	(1.84)	(1.71)	(1.60)
AVERS	.00	.00	.00	.00
	(.18)	(1.20)	(.86)	(.85)
CAP	-.01	-.02	-.01**	-.04**
	(-1.15)	(-1.15)	(-3.43)	(-3.66)
DFI	.40**	1.01**	.27*	.83**
	(2.23)	(2.29)	(1.69)	(2.08)
TLINE	-.08	-.20	.01	.02
	(-1.07)	(-1.16)	(.12)	(.15)
CELL	-.00	-.01	-.04	-.12
	(-.05)	(-.05)	(-.59)	(-.72)
FMS	.25**	.62**	.25**	.64**
	(3.59)	(3.63)	(4.09)	(4.12)
SPEC	-.09	-.24	-.01	-.98
	(-1.63)	(-1.62)	(-.26)	(-.48)
ENER	4.68	11.15	24.30**	59.38**
	(.40)	(.39)	(3.12)	(3.18)
SCI	.42*	.94*	.66**	1.59**
	(1.81)	(1.69)	(3.39)	(3.26)
R^2	47.4	49.6	47.2	49.8
Adj.R^2	29.3	32.2	29.1	32.5

Table 5.10 Determinants of international competitiveness
(seemingly unrelated equations model results)

	Model NXR		Model LNXR	
Variables	NXR79	NXR84	LNXR79	LNXR84
EFFMT	4.83*	3.31	2.10*	1.58*
	(1.69)	(1.47)	(1.77)	(1.65)
AVERS	.00	.00	.00	.00
	(1.36)	(1.04)	(.64)	(1.05)
CAP	-.003	-.01	-.00	-.00
	(-.18)	(-1.17)	(-.05)	(-.88)
DFI	.60	.36	.22	.07
	(1.54)	(1.01)	(1.37)	(.44)
TLINE	-.25	-.08	-.09	-.03
	(-1.53)	(-.48)	(-1.43)	(-.47)
CELL	.03	-.01	.01	.01
	(.20)	(-.06)	(.29)	(.18)
FMS	.56**	.49**	.23**	.20**
	(3.64)	(3.18)	(3.61)	(2.97)
SPEC	-.16	.01	-.06	.01
	(-1.27)	(.05)	(-1.21)	(.28)
ENER	11.02	44.13**	5.35	18.28**
	(.53)	(2.67)	(.63)	(2.59)
SCI	.57	.94**	.27*	.38**
	(1.59)	(2.63)	(1.81)	(2.45)

Table 5.11 Determinants of international competitiveness
(OLS results, outlier industries, SIC 346A and 372A, are excluded)

	Dependent variables			
Variables	NXR79	LNXR79	NXR84	LNXR84
EFFMT	2.77**	6.91**	2.02*	4.59*
	(2.03)	(2.09)	(1.72)	(1.70)
AVERS	.00	.00	.00	.00
	(.42)	(1.02)	(.57)	(.61)
CAP	-.01	-.02	-.01**	-.03**
	(-.72)	(-.76)	(-1.99)	(-2.18)
DFI	.40**	1.03**	.24	.76
	(1.97)	(2.08)	(1.19)	(1.63)
TLINE	-.15*	-.39**	-.06	-.16
	(-1.93)	(-2.08)	(-.69)	(-.78)
CELL	-.02	-.05	-.05	-.14
	(-.26)	(-.27)	(-.61)	(-.75)
FMS	.27**	.67**	.24**	.60**
	(3.85)	(3.99)	(3.15)	(3.40)
SPEC	-.06	-.15	.02	.02
	(-1.03)	(-1.06)	(.30)	(.17)
ENER	51.55**	128.67**	50.03**	128.50**
	(2.81)	(2.90)	(3.56)	(3.97)
SCI	.45**	1.02**	.67**	1.62**
	(2.27)	(2.11)	(3.13)	(3.30)
R^2	60.4	62.8	56.0	60.5
Adj.R^2	45.7	49.0	39.7	45.9

Table 5.12 **Determinants of international competitiveness** (OLS results, those industries that have low value of total trade are excluded)

	Dependent variables			
Variables	NXR79	LNXR79	NXR84	LNXR84
EFFMT	2.46	6.51^{*}	2.17^{*}	5.03^{*}
	(1.51)	(1.70)	(1.72)	(1.72)
AVERS	.00	.00	.00	.00
	(.36)	(.94)	(.60)	(.66)
CAP	.001	.00	-.01	-.03
	(.08)	(.13)	(-1.55)	(-1.65)
DFI	$.43^{*}$	1.13^{**}	.26	.82
	(1.94)	(2.19)	(1.08)	(1.48)
TLINE	$-.22^{**}$	$-.58^{**}$	-.08	-.21
	(-2.43)	(-2.76)	(-.86)	(-.96)
CELL	-.09	-.24	-.10	-.24
	(-.89)	(-1.00)	(-.94)	(-1.00)
FMS	$.26^{**}$	$.68^{**}$	$.25^{**}$	$.63^{**}$
	(3.18)	(3.53)	(3.03)	(3.31)
SPEC	-.10	$-.29^{*}$	-.04	(-.11)
	(-1.46)	(-1.77)	(-.47)	(-.59)
ENER	52.98^{**}	132.46^{**}	46.55^{**}	120.43^{**}
	(2.83)	(3.00)	(3.06)	(3.43)
SCI	$.49^{**}$	1.11^{**}	$.66^{**}$	1.58^{**}
	(2.28)	(2.19)	(2.87)	(2.98)
R^2	63.2	67.7	58.0	62.5
Adj.R^2	47.1	53.7	39.7	46.1

Notes: In 1979 equations, those industries that have total trade less than 750 million $ (SIC 341, 346A, 343, 381, 373, and 359), and in 1984 equations, those industries that have total trade less than 1,000 million $ (SIC 346A, 341, 343, 373, 381, and 374) are excluded from the sample.

Table 5.13 Determinants of international competitiveness (probit results)

	Dependent variables			
Variables	NXR79	NXR79	NXR84	NXR84
EFFMT	14.86	13.52*	12.95*	10.18*
	(1.22)	(1.67)	(1.70)	(1.80)
AVERS			-.00	
			(-.22)	
CAP	-.12		-.09**	-.05**
	(-.83)		(-1.86)	(-1.96)
DFI	3.21	1.76	1.20	.98
	(1.46)	(1.23)	(1.07)	(1.07)
TLINE	-.51		.39	
	(-.75)		(.90)	
CELL	-.15		-.51	
	(-.19)		(-1.15)	
FMS	2.27*	1.78**	1.23**	1.03**
	(1.84)	(2.21)	(2.29)	(2.36)
SPEC	-1.17*	-.77*	.09	
	(-1.79)	(-1.85)	(.27)	
ENER	495.36*	395.22**	225.40*	175.67**
	(1.77)	(2.08)	(1.90)	(2.00)
SCI	12.97	8.48**	5.16**	3.31**
	(1.64)	(2.18)	(2.02)	(2.58)
Log of likelihood function	-9.55	-10.83	-15.95	-17.32

Table 5.14 Determinants of international competitiveness (pooled data)

Variables	NXR	NXRTR
EFFMT79	2.63** (2.30)	2.85** (2.63)
EFFMT84	1.76** (2.66)	2.24** (3.44)
AVERS	.00 (.33)	-.00 (-.75)
CAP	-.01** (-2.29)	-.01** (-2.15)
DFI	.30** (2.22)	.25** (1.94)
TLINE	-.04 (-.81)	-.04 (-.74)
CELL	-.02 (-.44)	-.03 (-.68)
FMS	.24** (4.62)	.24** (5.04)
SPEC	-.05 (-1.21)	-.04 (-1.14)
ENER	15.73** (2.53)	43.69** (4.35)
SCI	.52** (3.59)	.65** (4.35)
R^2	46.4	53.2
Adj.R^2	37.7	45.1
u-statistic	.66	.48

5.4. Conclusions

The interrelations between machine tool users and producers were examined in this chapter. There are two major conclusions that were obtained from this analysis. First, it was found that there is an inertia in the decision rules of machine tool users in the adoption of new relations with machine tool producers. This result was supported indirectly by the positive and significant effect of U.S. outward-DFI on machine tool imports from the U.S. (Tables 5.2 and 5.3). Second, the U.S. engineering industries were negatively affected during the early 1980s as shown in the positive and significant coefficient of the EFFMT variable in the regression estimates of the model on the determinants of international competitiveness (Tables 5.7-5.13). This result is robust with respect to the estimation methods and assumptions. Moreover, no decline in the impact of a weak domestic machine tool industry was found during the period of 1979-1984. This result poses the problem of the importance of proximity to technologically advanced machine tool producers for the international competitiveness of users, which will be analyzed in the following chapter.

CHAPTER 6

CAUSALITY RELATIONS BETWEEN THE MACHINE TOOL AND ENGINEERING INDUSTRIES

6.1. Introduction

The development of the machine tool industry in the currently developed countries coincides with the development of engineering industries and with the process of industrialization in general. The emergence of the first 'modern' machine tool, J.Wilkinson's boring machine that enabled the manufacturing of J.Watt's steam engine, was among the major events that launched the Industrial Revolution. From that time on, the technological changes in the machine tool and engineering industries have been intertwined.

> More specifically, it can be said that the pace of development of machine tools governed the pace of industrial development. ... The share of machine tools in total manufacturing output is negligible, and even in the output of non-electrical machinery, it is much less than 10 per cent in most countries. However, in terms of a country's development, machine tools play a crucial

> role. ... As production of any machine used in the economy depends heavily on machine tools, it is evident that the machine tool is the basis of our whole mechanized society (UNIDO, 1984: 57).

Most historians would agree with this description of the relationship between the machine tool industry and the engineering industries in general, abstract terms. However, the question considered in this thesis is not on the relationship between these industries per se, but on the implications of (non)existence of a *domestic* machine tool industry: What is the role of the indigenous machine tool industry in the development of domestic engineering industries?

In Chapter 2, the argument in favor of a domestic machine tool industry is summarized in a testable hypothesis as follows. The development of domestic machine tool industry stimulates the development of domestic engineering industries by i) satisfying closer producer/user interactions (lowering transaction costs involved in the search process, exchange of design information, better maintenance services, etc.), ii) creating some external economies, and iii) fulfilling the development potentials hidden under the various forms of interdependencies. It is also argued that highly developed engineering industries (EI) are also imperative for the development of domestic machine tool industry (MTI) because of the very same reasons. Accordingly, there may be bidirectional causality flows such as MTI => EI, and EI => MTI.

The existence of bidirectional causality relations between the domestic machine tool industry and engineering industries is a theoretical possibility. But even if these relations exist, their magnitude and influence may be practically insignificant and unrecognizable. Thus, in this Chapter, these bidirectional causality relations are investigated to find out whether they are significant enough to be detected by statistical methods. A simple model of relations between machine tool production and engineering goods output is developed in Section 6.2. The results of causality tests for FRG, Japan, Sweden, and the U.S. were examined in Section 6.3. Section 6.4 concludes the chapter. A short methodological summary of causality tests and the concept of Granger causality is given in the Appendix.

6.2. A Model of the Causality Relationships

As explained in the Appendix, there are two approaches to causality testing. The classical econometric approach requires an a priori theoretical framework for the construction of a model in which causality relations can be tested. The test applied in Chapter 5 on the effects of weakening U.S. machine tool industry on the domestic engineering industries after the mid-1970s can be given as an example of this approach. The second, time series approach requires a minimum amount of a priori information on the relationships between economic variables.

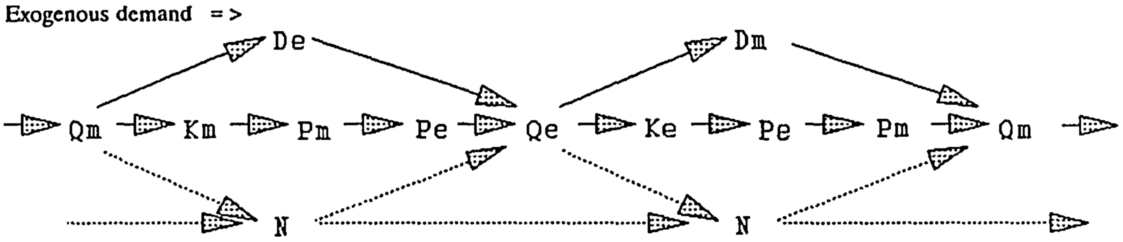
In this chapter, long-term causality relations between the development of the domestic machine tool industry and engineering industries are tested. But unfortunately there is almost no study on modelling the dynamic relationships between these industries in the process of industrial development. Previous studies have been focused on either some general correlations between aggregate economic variables (e.g. the correlation between machine tool production and GNP) without explicit construction of causality relations, or highly detailed descriptive/historical studies of the industry. The reason for this lack of modelling effort is the complexity of interactions and linkages between these industries. Accordingly, in this study, the time series approach seems to be more informative in searching for causality relations between the machine tool industry and engineering industries.

A bivariate dynamic simultaneous equations model was used for this purpose. The time series considered in this model are output values for the machine tool industry and engineering industries. The possible linkages joining these series are analyzed in this section to determine a priori structures that may arise in the model. Some implications of this analysis are also investigated to support the results of causality tests and to shed light on possible connections between time series that carry out causality relations implied in the model.

The interactions between the development of the machine tool industry and the engineering industries constitute an endless loop in the industrial development process which runs from machine tool production to engineering goods production and back to machine tool production. A simple model of this loop is depicted in Figure 6.1.

At any time point in this loop, domestic machine tool production has three immediate effects. First, machine tool production creates demand for engineering goods through input-output relations (Q_m -> D_e). Recall that almost all inputs used by the machine tool industry are produced by the engineering industries. The second immediate effect of machine tool production is the accumulation of technological knowledge concerning the design and production of machine tools (Q_m -> K_m). By this process, machine tool firms gradually expand their technological positions into new areas and reduce their product costs, and/or improve their products currently being produced (K_m -> P_m). The third effect is on the network of relations that embrace machine tool producers, users, and supporting (especially, subcontractor) firms (Q_m -> N). These effects may be in the form of increasing specialization, external economies, and increase in the intensity of non-market mediated information flows and coordination that help to reap the benefits of various interdependencies, as summarized in Chapter 2.

Figure 6.1 **A model for the relationships between machine tool and engineering goods production**



These three effects create pressures on demand and supply so that the production of engineering goods increases. The input requirements of machine tool production and exogenous demand (demand by other sectors of the economy) generate engineering goods production (D_e -> Q_e). Increasing machine tool quality and low machine tool costs may increase the productivity of engineering industries (P_m -> P_e), thereby increasing its relative size in the economy (P_e -> Q_e). The contributions to the network of relations affect engineering goods output in a similar way (N -> Q_e). Domestic machine tool production does not necessarily generate the *domestic* engineering goods production. Only to the extent that transaction costs involved in these relations are significant, and that the influence of geographical and cultural/legal proximity is important for the fluidity of information flows, can domestic production be favored relative to import demand.

An increase in domestic engineering goods production may have a similar impact on the development of the domestic machine tool industry. First, it may contribute to the development of the network of relations and

First, it may contribute to the development of the network of relations and facilitate various forms of coordination of economic activities within local/national economies (Q_e -> N ->Q_m). Second, the accumulation of knowledge as a result of productive activities may improve the quality of engineering goods that, in turn, increases the quality of machine tools and machine tool production (Q_e -> K_e -> P_e -> P_m -> Q_m). And, third, the production of engineering goods requires machine tools (Q_e -> D_m -> Q_m). Then, the new demand for machine tools activates another loop in the process of economic growth.

The demand for machine tools has some special characteristics that have major implications in this context. As capital goods, machine tools are required for the production of engineering goods and demanded either for replacement (depreciation) or for expansion (net investment). But, more significantly, the demand for machine tools is influenced by the quality of machine tools in a specific way. New machine tool designs, by offering an improved method of operation can make a part of total machine tool stock technologically obsolete even though they are not worn out physically. Thus, machine tool firms may expand the demand for machine tools by deliberately developing new designs. Brown (1957) argues that 'both the introduction of new machine tools and the timing of their introduction can be understood as a planned attempt on the part of the machine tool firm to increase demand for its product'. Machine tool firms collect the information during the production process on a 'shelf of design ideas' and when the demand for machine tools falls, they start to introduce new designs by an intensified research and design process involved in moving from the shelf of ideas to actual designs. Brown cites the movement of the value of total machine tool shipments in the opposite direction from the number of new designs introduced in the U.S. machine tool industry in the first half of the 20th century as evidence for this thesis.

Whether machine tool firms introduce new designs when machine tool demand falls, though an interesting argument by itself, is not crucial in our exposition of the relationships between the machine tool industry and the engineering industries. The vital conclusion that can be used in the interpretation of causality tests is the lagged effect of machine tool production. The direct input demand for engineering goods created by machine tool production is insignificant compared to exogenous demand. The most noticeable impact of machine tool production on the engineering industries will be through improved, new machine tools and the contributions to the network of relations (externalities and interdependencies). On the other hand, the production of engineering goods has an immediate effect on machine tool production for a definite time period. In brief, the causality running from machine tool production to engineering goods production, if it exists, may be expected to be in a lagged form, i.e., 'causality lag' as defined by Granger. For causality running from the engineering industries to the machine tool industry, lower-order lags of engineering products may have greater effects on the production of machine tools.

Before applying causality tests, some of the stylized facts implied by the model developed here should be examined to show the relevance of these relations. The first fact that may be expected is on the correlation between industrial development and machine tool production capabilities.

Table 6.1 Machine tool manufacturing capability at various stages of industrial development

Limited	Moderate	Substantial	High
Bench drills Bench grinders Sheet-metal-forming machines	Engine lathes Simple milling machines Bench and pillar drilling machines Surface-grinding machines Tool and cutter grinding machines Shaping machines Hacksawing machines Small mechanical presses and brakes	Turret lathes Automatic lathes, bar and chuck type Tracer lathes Precision grinding machines Milling machines Horizontal boring machines Jig-boring machines Gear-hobbing machines Broaching machines Radial drilling machines Screwing machines Hydraulic or mechanical presses	Gear-grinding machines Special-purpose machines Transfer machines NC drilling machines NC boring machines NC lathes Electrochemical milling machines Other types according to demand

Source: UNIDO, 1974: 21

If machine tool design and production capabilities are obtained in a cumulative process of production and learning, only industrially developed countries may be expected to have technological capabilities for economical production of relatively sophisticated machine tools. Table 6.1 lists the types of machine tools that can be built at four different stages of industrial development according to a UNIDO study on the machine tool industry. Although there are some inter-country differences, this table represents a useful description of technological capabilities. The differences in production structures between less developed and developed countries are very distinct. Production is heavily concentrated on simple lathes and drilling machines in the less developed countries whereas the share of more sophisticated machine tools (gear-cutting and grinding machines, NC machine tools, etc.) is higher in the developed countries.

In addition to the correlation between machine tool production capabilities and industrial development, a positive correlation between the international competitiveness in machine tools and engineering goods may be expected if the well-being of these industries are interdependent. Figure 6.2 depicts the plot of net export ratios in machine tools vs. in engineering industries for seventeen major machine tool producing countries. The correlation coefficient between two variables is .85 which is statistically significant at the 1% level.[1]

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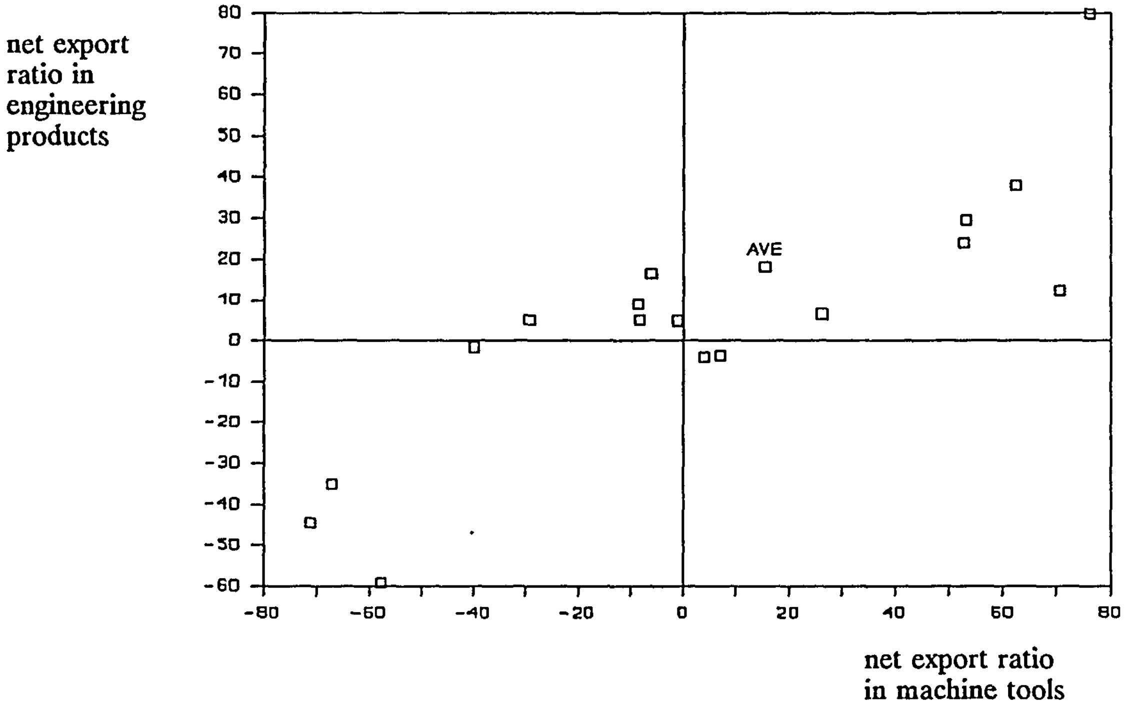
[1] Of course, there are some other factors that may explain the correlation between these two variables. For example, if the production requirements of machine tools and engineering goods are similar, such a correlation may be expected. For this reason, it is necessary to use explicit causality tests to analyze the linkages between the machine tool industry and the engineering industries.

Figure 6.2 **Net export ratio in machine tools vs. net export ratio in total engineering products (1984)**



Source: UN, *Yearbook of International Trade Statistics* (1984).

The international competitiveness in these fields comes from the size of the industry (the degree of specialization and the extent of network relations), and the volume of cumulative output (the development of technological capabilities). This proposition can be tested for machine tool production in a simple linear regression model by using pooled data for 7 major developed countries for the period 1969-1988 as follows.

[6.1] $TP_{ij} = a_1QCUM_{ij}$ + (country dummy variables) + e_{ij} , $i=1,...,T$, $j=1,...,N$, where subscripts i and j denote time and country, respectively. The net export ratio is used to measure trade performance (TP). Cumulative output is used relative to total cumulative output to reflect the effects of relative accumulation of knowledge on trade performance. The accumulation period was arbitrarily restricted to five years. (However, this restriction does not have any noticeable effect on the regression results.) Thus, $QCUM_{ij}$ is defined as follows.

[6.2] $QCUM_{ij} = \Sigma^4_{k=0}Q_{(i-k),j}/\Sigma^4_{k=0}Q^w_{(i-k)}$, where Q^w_i is total world machine tool output at time i.

To measure country-specific attributes, dummy variables for each country were also included in Equations 6.1.

A positive relationship between *changes* in relative cumulative output ratio and *changes* in trade performance (international competitiveness) may also be expected according to the same proposition. Another linear regression model was estimated to test this expectation

[6.3] $CTP_{ij} = a_1CQCUM_{ij}$ + (country dummy variables) + e_{ij} , where $CTP_{ij} = ln(XSHR_{ij}/XSHR_{i-1,j})$ and $CQCUM_{ij} = ln(QCUM_{ij}/QCUM_{i-1,j})$. $XSHR_{ij}$ is the share of the jth country's machine tool exports in total world exports at time i. In this equation, the change in export share is used instead of the change in net export ratio since the latter variable is undefined for negative values.[2]

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[2] Data for machine tool production and trade are obtained from *American Machinist*, various issues.

The estimation results of Equations 6.1 and 6.3 are shown in Table 6.2. In both equations, the coefficient of the relative cumulative output variable is statistically significant at the 5% level.[3] This result supports the argument that cumulative machine tool output may have a positive impact on the international competitiveness in machine tools.[4]

Correlations between i) the level of industrial development and machine tool production capabilities, ii) international competitiveness in engineering goods and machine tools, and iii) (changes) in cumulative machine tool output and (changes) in international competitiveness in machine tools are suggestive of the linkages between the production of machine tools and that of engineering goods, although they are not sufficient to establish causality relations between these industries. In the following section, causality relations based on Granger's definition are tested for this purpose.

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[3] Note that the usual assumptions of OLS estimation may not be satisfied in these cases since heteroscedasticity, autocorrelation, and contemporaneous covariance may exist as a result of combining time-series and cross-sectional data.

[4] The country dummy variables in Equation 6.1 show the relation between the shares in the world cumulative machine tool output and in the world export shares. In other words, a country that has a low dummy coefficient in Equation 6.1 has a low export participation relative to its share in the world machine tool output. As may be expected, small countries (Switzerland, Italy, and Sweden) have higher values for this coefficient. Similarly, the country dummy variables in Equation 6.3 represent country-specific effects of learning on changes in the export market share. For example, Japan, Switzerland, and Italy that have the highest values for the coefficient of dummy variables tend to increase their market shares more than other countries. But recall that these results should be interpreted with caution because the estimators of these coefficients may be biased and inefficient as stated in Footnote 3.

Table 6.2 Effects of cumulative machine tool production on international competitiveness

Variables	Dependent variables TP	 CTP
QCUM	13.24^{**}	
	(8.53)	
CQCUM		$.333^{**}$
		(1.99)
D1 (United States)	-2.43^{**}	$-.064^{**}$
	(-8.63)	(-2.01)
D2 (United Kingdom)	$-.48^{**}$	-.040
	(-3.95)	(-1.29)
D3 (Switzerland)	1.05^{**}	-.016
	(9.12)	(-.52)
D4 (Sweden)	$-.28^{**}$	-.035
	(-2.82)	(-1.15)
D5 (Japan)	$-.45^{*}$	.051
	(-1.86)	(1.60)
D6 (Italy)	.04	-.032
	(.27)	(-1.03)
D7 (FRG)	$-.82^{**}$	-.037
	(-2.82)	(-1.22)
R^2	85.9	16.8
Adj.R^2	85.0	10.8

6.3. Results of Granger-causality Tests

In practice, Granger tests are based on the estimation of bivariate dynamic simultaneous equations model as in Equation A.2 in the Appendix.[5] The time

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[5] A constant term can be added for each variable in Equation A.2 in the Appendix without affecting any properties of the model.

series used in our tests are annual output data for the machine tool industry and engineering industries for FRG, Japan, Sweden, and the U.S.[6] Since there were obvious trends in the logarithm of the data, first differences (annual growth rates) were found to detrend the data. The plots of the data, as shown in Figures 6.3-6.6 indicate that there is no significant trend left. These figures show clearly that the growth rate in machine tool output moves in the same direction as the growth rate in engineering production.[7] This may indicate that instantaneous causality can exist. Moreover, the use of annual data can increase this possibility.

Akaike's final prediction error (FPE) and Schwarz's Bayesian information criterion (SC) were determined for each country by fitting one-dimensional autoregressive processes (E and T processes for time series of annual growth rates in engineering goods and machine tools, respectively).[8]

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[6] Data for the output of engineering industries are obtained from U.N., *Industrial Statistics Yearbook*, and machine tool data from *American Machinist*, related issues. Machine tool data are converted into production in local currencies by using exchange rates given by IMF, *International Financial Statistics*. U.S. data are aggregated from monthly data obtained from BEA, *Survey of Current Business*, related issues. U.S. data cover only metalcutting machine tools.

[7] These figures also reveal a well-known fact that fluctuations in growth rates of machine tool production is much more excessive than those of engineering goods. Fluctuations in the growth rate of U.S. machine tool output is relatively higher. This may be as a result of low level of trade participation of the U.S. machine tool industry since there is a significant negative correlation between fluctuations in machine tool output and export-output ratio of a country.

[8] These criteria are defined as follows.

$\mathrm{FPE} = \hat{\sigma}^2(N+d)/(N-d)$ and $\mathrm{SC} = ln(\hat{\sigma}^2) + d\,ln(N)/N$, where $\hat{\sigma}^2$ is the residual variance, N the number of observations, and d the number of the right-hand side variables including the constant term.

Figure 6.3 Growth rate in machine tool and engineering goods output in FRG

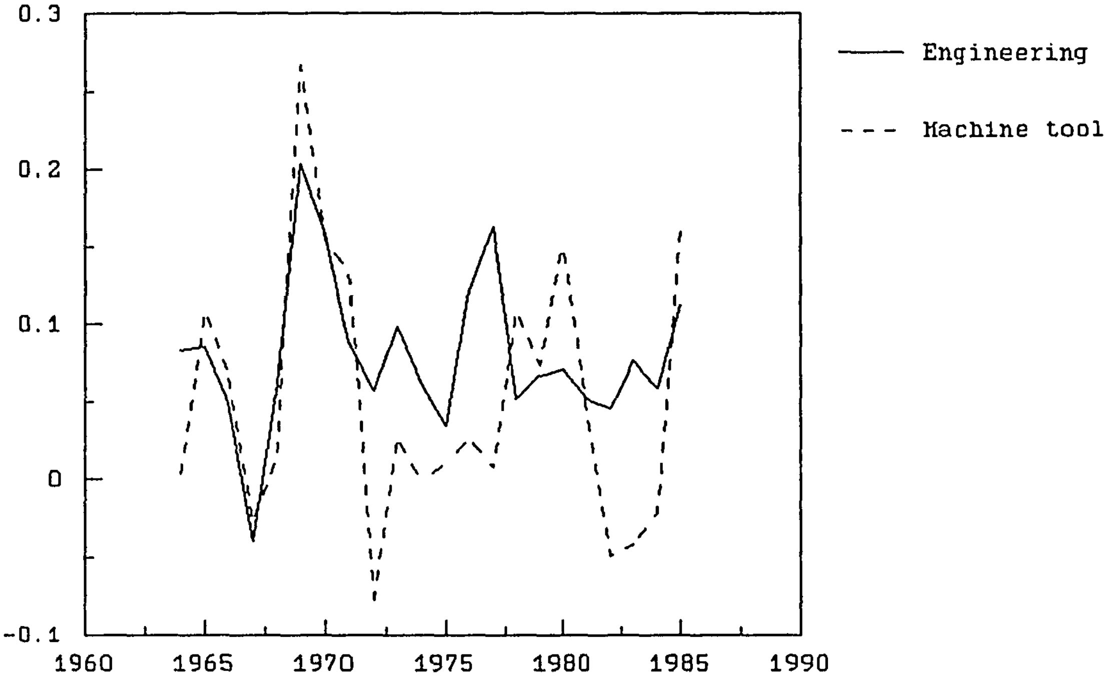


Figure 6.4 Growth rate in machine tool and engineering goods output in Japan

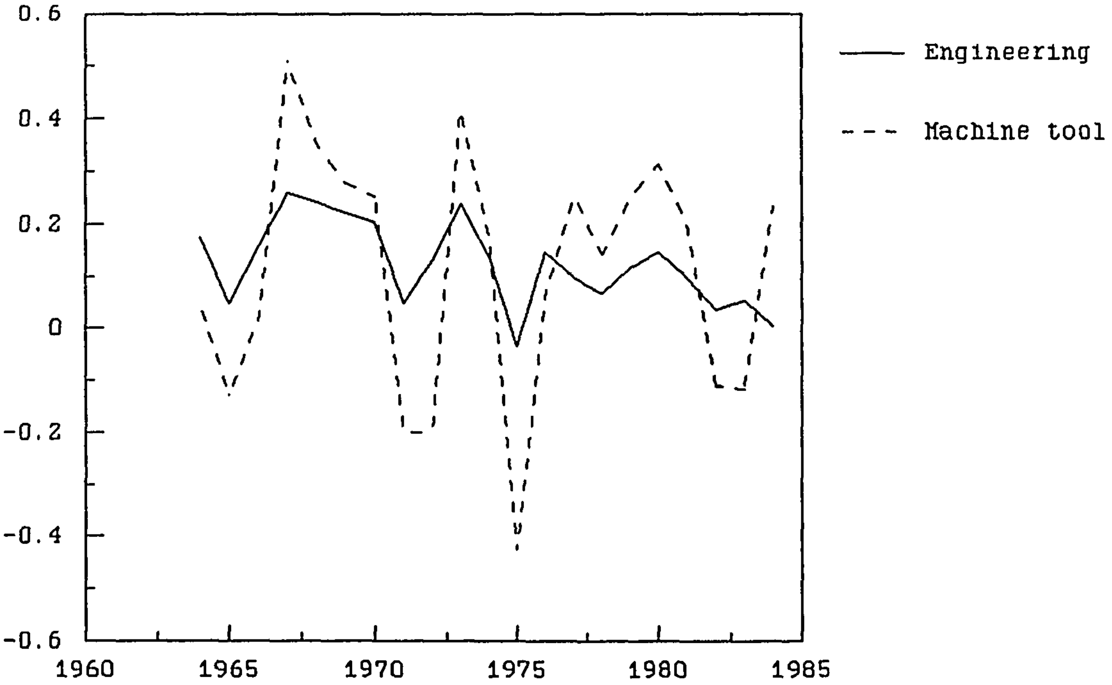


Figure 6.5 Growth rate in machine tool and engineering goods output in Sweden

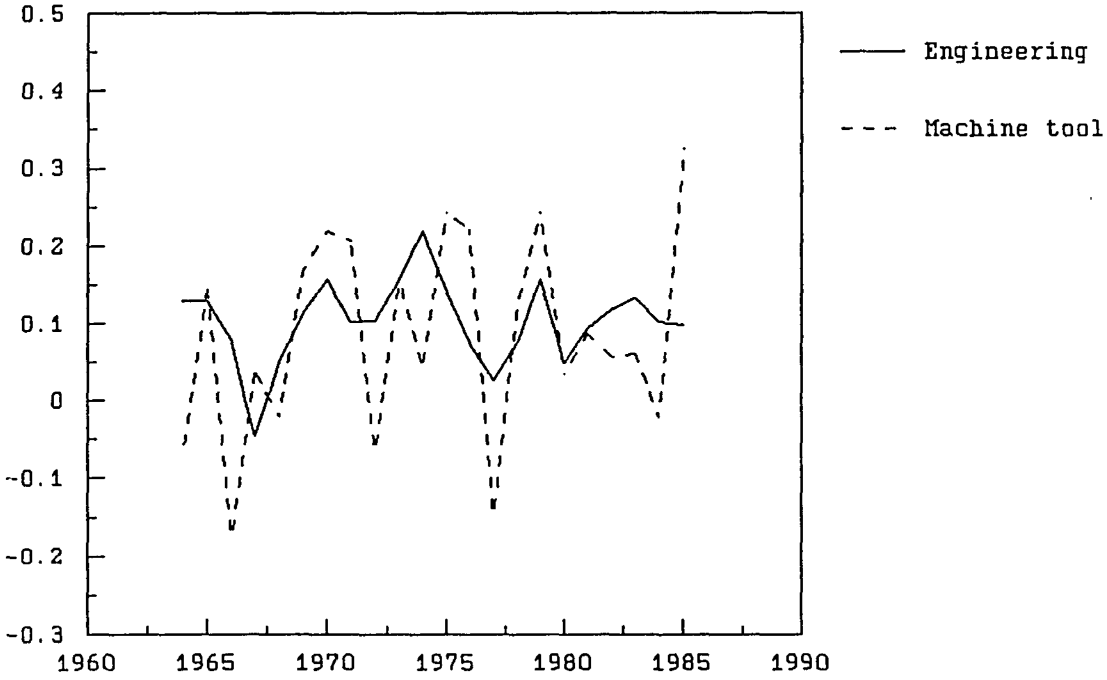
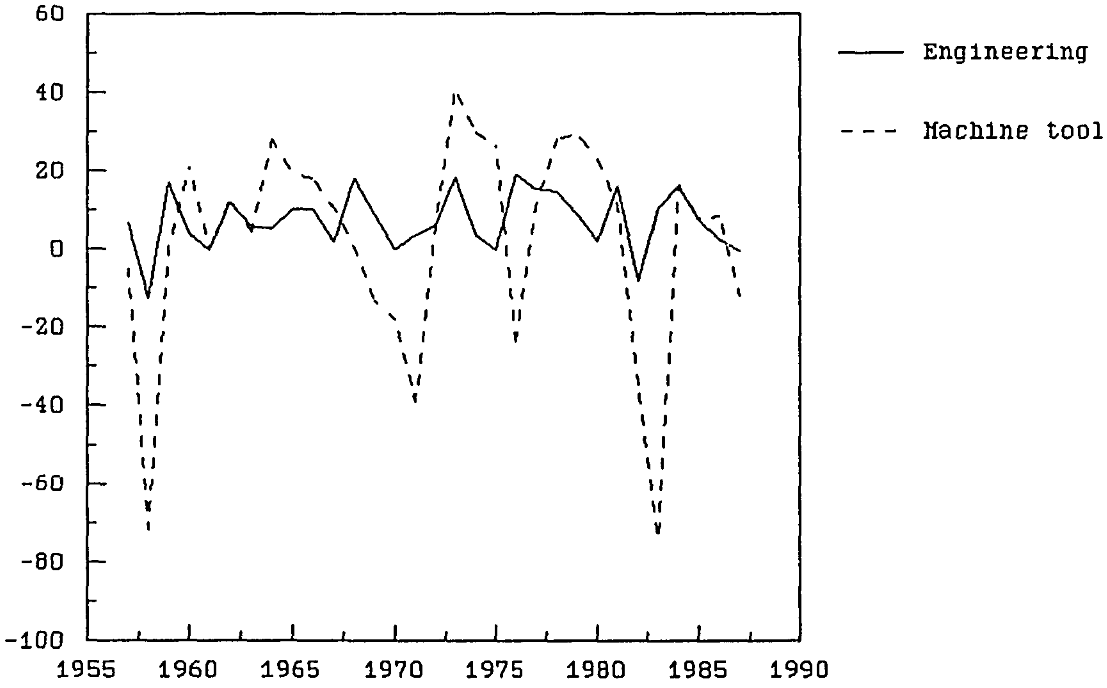


Figure 6.6 Growth rate in machine tool and engineering goods output in the U.S.



The maximum order length was a priori set to four to restrict the range of alternatives. Since it was found that all processes (except T process of Japan) have lower lag orders, this restriction seems to be acceptable. Both criteria selected the same lag order for all processes except only T process for FRG (Part (a) of Tables 6.4-6.7). Since the FPE (SC) criterion tends to overfit (underfit) the lag order, the results are robust with respect to the order selection criterion.

The FPE criterion includes a new lag in the equation if it decreases the (asymptotic) mean square prediction error. Note that this method of choosing the lag order (and, in this manner, SC criterion, too) is equivalent to applying sequential F-tests with varying significance levels. The advantage of this method over the conventional hypothesis testing procedure where the choice of significance level is ad hoc (generally 5% or 1% level) is the use of an explicit optimality criterion (Hsiao, 1979a and 1979b; Saunders, 1988). In many practical cases, the implicit significance levels of the FPE criterion are higher compared to F-tests (10% to 30% levels).

In the second step, the process found in the first step was treated as a controlled variable and the optimum lag structure of the second (manipulated) variable was determined by using McClaves (1978) ‘max X^2’ (maximum Chi-square) method. This method can select a subset of lags whereas Hsiao’s method determines lags in a sequential manner ({1}, {1,2}, ... {1,2,...,K}). For example, the former method can select the set of optimum lags in arbitrary order such as {1,4}, but, in the later method, all lags up to the maximum ordered lag should be included in the optimum set. Since there may be lagged causality as predicted by the model developed in Section 6.2, McClave's method seems to be more appropriate in this step.

In the max X^2 method, the first stage is to determine the subset of 'best' AR model of each order $k \in \{1,2,\ldots,K\}$, where K is the maximum lag of the expected model (K=4 in our case). The 'best' model for each order k is defined as that subset AR model with minimum residual variance, $\hat{\sigma}^2_k$. Let's define this subset as $\Phi_1, \Phi_2, \ldots, \Phi_K$, where $\Phi_k = \{l_1, l_2, \ldots, l_k\}$, and l_i is the l_i^{th} lag in the subset. The test statistic used to choose the optimum lag structure among the subsets, Φ_k, is defined as

$M^*_{k+1} = (N-k-s-1)(\hat{\sigma}^2_k - \hat{\sigma}^2_{k+1})/\hat{\sigma}^2_{k+1}$, where $\hat{\sigma}^2_k$ is the residual variance corresponding to Φ_k, and s is the number of parameters used in the model in addition to the lags of the manipulated variable. The optimum lag structure, Φ_k, is chosen such that

$$k^* = \{\min k;\ M^*_k \leq c_k,\ 0 \leq k \leq K\}.$$

For a given level of significance, c_k is determined such that $P\{M_k > c_k\} = \alpha$, where M_k is the maximum order statistic in a sequence of (K-k) independent X^2_1 random variables.

The critical values are determined by solving

$P\{|Z| \leq \surd c_k\} = \alpha^{[1/(K-k)]}$ for c_k, where Z is a standard normal random variable (McClave, 1978: 126). Critical values of max X^2 are as follows for K=4.

	$\alpha = .10$	$\alpha = .20$
k=0	5.15	3.71
k=1	4.46	3.24
k=2	3.78	2.62
k=3	2.71	1.64

This order statistic is found by assuming ordered statistics M^*_k are independent. Since they are not independent, the max X^2 method may yield a conservative test. Moreover, as stated above, the F-statistic corresponding to the FPE criterion has a higher significance level than the conventional 5% or 1% levels. For these reasons, 10% and 20% significance levels of max X^2 are reported in the following tables.

Part (b) of Tables 6.4-6.7 shows the FPE, SC, and max X^2 statistics for the 'best' subsets of the manipulated variable. After selecting the optimum lag structure of the manipulated variable, bivariate models for each country were determined. Full information and OLS estimates of models are presented in Part (c). In order to check the adequacy of selected models, a sequence of likelihood ratio tests was carried out against fitted lower- and higher-order AR processes (Part (d) of each table). Critical values of X^2 used in the maximum likelihood ratio tests are as follows.

	$\alpha = .05$	$\alpha = .10$
Degrees of freedom: 1	3.84	2.71
Degrees of freedom: 2	5.99	4.61

The X^2 statistics used in diagnostic checking indicate that the selected models are usually appropriate. Test results for each country can be summarized as follows.

6.3.1 FRG (1968-1985)[9]

Statistics of fitting one-dimensional AR E and T processes for FRG are shown in Table 6.4a. For the E process, both the FPE and SC criteria select 2nd order AR process. For the T process, the FPE criterion selects 3rd order lag whereas the SC criterion selects 1st order. Since the difference between SC criteria for 1st and 3rd order T processes is very small, T(3)[10] process was selected for further steps.

E(2) and T(3) processes were treated as controlled variables, and the optimum lag structures of other (manipulated) variables were determined by using the FPE, SC, and max X^2 criteria. As shown in Table 6.4b, all three criteria reject the addition of a manipulated variable. (For example, for E(2) process, when the 'best' single-lag T process (T4) was added into the equation, both the FPE and SC criteria deteriorated (FPE, from 16.956 to 17.766, SC, from 2.976 to 3.068). The max X^2 statistics for both processes are not

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[9] Dates in the parenthesis refer to the time period of the dependent variables. In other words, original data set go back 5 more years that this period (one observation for the calculation of growth rate, and four observations for lagged variables).

[10] T(3) means third order AR process of T. In other words,

$$T_i = \alpha_0 + \alpha_1 T_{i-1} + \alpha_2 T_{i-2} + \alpha_3 T_{i-3} + \epsilon_i.$$

statistically significant at the 20% level. Therefore, tentatively, the E(2) and T(3) processes are selected. This result implies that there is not any Granger-causality running from E to T, and T to E processes.

FIML and OLS estimates of these processes are shown in Table 6.4c. Likelihood ratio tests against lower and higher order AR processes were carried out for diagnostic checking purposes (Table 6.4d). The X^2 statistics of tests with lower order processes indicate that the data do not show simpler processes than E(2) and T(3) (likelihood ratios for lower-order models, M 1 and M 2, are statistically significant). On the other hand, the likelihood ratio of one higher-order model, M 5, is also statistically significant at the 10% level. This result may indicate that the E(2)/T4[11] and T(3)/E2 model may fit the data better than the E(2) and T(3) model. When the E(2)/T4 and T(3)/E2 model was estimated, it was found that the t-statistics of manipulated variables were not significant either. Thus, the E(2) and T(4) model (no causality in both directions) seems to be preferable to the E(2)/T4 and T(3)/E2 (bidirectional causality). Note that the E(2) and T(4) model does not exclude the possibility of instantaneous causality. Since a lagged-causality running from T to E process is expected, this possibility may not be a serious problem.

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[11] E(2)/T4 means AR process of E with the second order lags of controlled variable (E) and the fourth lag of manipulated variable (T). In other words,

$$E_i = \alpha_0 + \alpha_1 E_{i-1} + \alpha_2 E_{i-2} + \alpha_3 T_{i-4} + \epsilon_i.$$

6.3.2 Japan (1968-1984)

Statistics of fitting one-dimensional AR E and T processes for FRG are shown in Table 6.5a. For the E and T processes, both the FPE and SC criteria select 1st and 4th order AR processes, respectively. Since the maximum lag order selected a priori was 4, the FPE and SC criterion for the T process was found for 5th order, too. Since the criteria for the 5th order process were higher than that of the 4th order process, T(4) process was selected for further steps.

E(1) and T(4) processes were treated as controlled variables, and the optimum lag structures of other (manipulated) variables were determined as shown in Table 6.5b. For the T process, all three criteria select T(4)/E1,3 model. For the E process, three criteria select different lag structures: the FPE selects E(1)/T1,4, the SC selects E(1)/T1, and the max X^2 selects E(1) models. But the difference in the SC criteria between E(1)/T1 and E(1)/T1,4 models is very small and the max X^2 statistic for both models is relatively higher, E(1)/T1,4 model seems to be appropriate. Thus, temporaryly, the E(1)/T1,4 and T(4)/E1,3 model was selected for the Japan. This result implies that there are bidirectional causality relations between E and T processes.

FIML and OLS estimates of these processes are shown in Table 6.5c. Likelihood ratio tests against lower and higher order AR processes were carried out for diagnostic checking purposes (Table 6.5d). The X^2 statistics of tests with lower- and higher-order processes indicate that the data do not show any serious deficiency of the selected E(1)/T1,4 and T(4)/E1,3 model.

6.3.3 Sweden (1968-1985)

Statistics of fitting one-dimensional AR E and T processes for Sweden are shown in Table 6.6a. For the E and T processes, both the FPE and SC criteria select 2nd and 1st order AR processes, respectively.

E(2) and T(1) processes were treated as controlled variables, and the optimum lag structures of other (manipulated) variables were determined as shown in Table 6.6b. For the E process, all three criteria select E(2)/T3 model. For the T process, the FPE and SC criteria select T(1)/E1 model and the max X^2 statistic is relatively high for this model though is not statistically significant. Thus, the E(2)/T3 and T(1)/E1 model was selected for the Sweden. This result implies that there are bidirectional causality relations between E and T processes.

FIML and OLS estimates of these processes are shown in Table 6.6c. Likelihood ratio tests against lower and higher order AR processes were carried out for diagnostic checking purposes (Table 6.6d). The X^2 statistics of tests with lower- and higher-order processes indicate that the data do not show any serious deficiency of the selected E(2)/T3 and T(1)/E1 model.

6.3.4 U.S. (1961-1987)

Statistics of fitting one-dimensional AR E and T processes for FRG are shown in Table 6.7a. For the E and T processes, both the FPE and SC criteria select 2nd and 1st order AR processes, respectively.

E(2) and T(1) processes were treated as controlled variables, and the optimum lag structures of other (manipulated) variables were determined as shown in Table 6.6b. For the E process, all three criteria select E(2)/T4 model. For the T process, again, all three criteria select same model, T(1)/E1 model. Thus, tentatively, the E(2)/T4 and T(1)/E1 model was selected for the U.S. This result implies that there are bidirectional causality relations between E and T processes.

FIML and OLS estimates of these processes are shown in Table 6.7c. Likelihood ratio tests against lower and higher order AR processes were carried out for diagnostic checking purposes (Table 6.7d). The X^2 statistics of tests with lower- and higher-order processes indicate that the data do not show any serious deficiency of the selected E(2)/T4 and T(1)/E1 model.

These tests for the U.S. were repeated by using quarterly data (the time period for the dependent variables covers 1961:1-1988:2). The model E(9)/T11,12 and T(11)/E3,4 was chosen to represent the bivariate model. Incidentally, the order of lags in the quarterly model roughly corresponds to those in the annual model. The quarterly model indicates bidirectional causality relations between the U.S. machine tool industry and engineering industries.

The degrees of freedom in the quarterly model are sufficient to perform Chow tests for structural change. Recall that the time period covered in our models is relatively long (from the early 1960s to the mid-1980s), and technological and economic development in these industries may change the model itself. To test the existence of structural change, the sample was divided into two periods, 1961:1-1975:4, and 1976:1-1988:2, by considering the fact that the most important change in the machine tool technology occurred in this period. The first microcomputer-based NC machine tool was manufactured in 1974. F-statistics were found from OLS estimations of restricted (same coefficients for both periods) and unrestricted (different coefficients for both periods) models. F-statistics for E(9)/T11,12, and T(11)/E3,4 equations were found as .74, and 1.40, respectively. Since neither statistic is statistically significant at the 10% level, the null hypothesis of no structural change can not be rejected. This result may be used to support the conjecture on the stability of bivariate models found in this section.

6.3.5 Summary of results

In brief, the models for each country can be selected as follows.

Country	*Model*	
FRG	E(2)	T(3)
Japan	E(1)/T1,4	T(4)/E1,3
Sweden	E(2)/T3	T(1)/E1
U.S.	E(2)/T4	T(1)/E1

Several comments on these models should be noted. First, although the model for FRG does not show any Granger-causality, another model, E(2)/T4 and T(3)/E2 seems to have a good fit to the data. But even if the former model for FRG is accepted, other models reveal that there are bidirectional causality relations between the production of machine tools and engineering goods. Second, and more surprisingly, these models support the conjecture developed in the preceding section on the causality lag running from machine tool production to engineering goods production. In all models (including the alternative model for FRG), the lag of the T process in the E equation is higher than that of the E process in the T equation. Third, the quarterly U.S. data reveal that there is not any structural change in the model in this period.

Table 6.4a Statistics of Fitting One-dimensional Autoregressive E and T Processes for FRG (1968-1985)

The order of lags	E Process FPE	E Process SC	T Process FPE	T Process SC
1	24.083	3.280	91.250	4.612
2	16.956	2.976	97.502	4.725
3	18.953	3.132	84.613	4.628
4	17.338	3.085	95.204	4.788

Table 6.4b The Optimum Lags of the Manipulated Variable and the FPE and SC of the Controlled Variable for FRG (1968-1985)

Controlled variable	Manipulated variable	Lags	FPE	SC	Max Chi2
E(2)	T	None	16.956	2.976	
		4	17.766	3.068	1.00
		2,4	19.815	3.219	0.12
		2,3,4	22.278	3.374	0.07
		1,2,3,4	25.290	3.533	0.01
T(3)	E	None	84.613	4.628	
		2	85.188	4.677	1.54
		1,2	94.800	4.822	0.19
		1,2,3	105.278	4.960	0.26
		1,2,3,4	117.274	5.094	0.27

Table 6.4c Autoregressive Estimates of E and T Processes for FRG (1968-1985)

Variable	FIML Estimates Coefficient	 t-statistic	OLS Estimates Coefficient	 t-statistic
E Process				
E1	.294	1.754	.354	2.016
E2	-.422	-2.046	-.520	-2.976
Std.err.	3.521		3.821	
T Process				
T1	.185	.310	.231	.951
T2	-.064	-.180	-.066	-.260
T3	-.457	-1.470	-.508	-2.027
Std.err.	7.362		8.320	

Table 6.4d Likelihood Ratio Tests Against Lower and Higher Order Autoregressive Processes for FRG

		Lower Order		Higher Order		
	Base	M 1	M 2	M 3	M 4	M 5
ϕ_{11}	1,2	1,2	1	1,2	1,2	1,2
ϕ_{12}	0	0	0	0	4	4
ϕ_{21}	1,2,3	1	1,2,3	1,2,3	1,2,3	1,2,3
ϕ_{22}	0	0	0	2	0	2
DoF		2	1	1	1	2
log(L)	-106.96	-109.84	-110.10	-106.15	-106.39	-105.52
LR		5.77*	6.28**	1.63	1.13	2.89*

Note: * (**) means statistically significant at 10% (5%) level.

Table 6.5a Statistics of Fitting One-dimensional Autoregressive E and T Processes for Japan (1968-1984)

The order of lags	E Process FPE	E Process SC	T Process FPE	T Process SC
1	65.762	4.283	639.64	6.558
2	73.714	4.444	534.38	6.424
3	74.042	4.492	562.72	6.520
4	84.021	4.658	449.13	6.334

Table 6.5b The Optimum Lags of the Manipulated Variable and the FPE and SC of the Controlled Variable for Japan (1968-1984)

Controlled variable	Manipulated variable	Lags	FPE	SC	Max Chi2
E(1)	T	None	65.762	4.283	
		1	62.252	4.274	2.68
		1,4	60.064	4.282	2.24
		1,2,4	65.515	4.409	0.49
		1,2,3,4	68.176	4.484	1.06
T(4)	E	None	925.79	7.058	
		3	478.35	6.433	13.28**
		1,3	367.62	6.198	4.94**
		1,2,3	418.58	6.348	0.15
		1,2,3,4	465.11	6.464	0.42

Note: ** means statistically significant at 10% level.

Table 6.5c Autoregressive Estimates of E and T Processes for Japan (1968-1985)

Variable	FIML Estimates Coefficient	t-statistic	OLS Estimates Coefficient	t-statistic
E Process				
E1	1.10	1.418	1.10	2.813
T1	-.266	-1.285	-.266	-2.068
T4	-.110	-1.283	-.110	-1.495
Std.err.	6.098		6.973	
T Process				
T1	-.0613	-1.284	-.866	-1.394
T2	-.403	-2.10	-.427	-1.611
T3	.699	2.455	1.075	3.061
T4	-.563	-2.291	-.705	-3.312
E1	2.806	2.291	3.646	2.222
E3	-2.549	-2.130	-3.850	-2.404
Std.err.	13.201		16.137	

Table 6.5d Likelihood Ratio Tests Against Lower and Higher Order Autoregressive Processes for Japan

		Lower Order					H.Order
	Base	M 1	M 2	M 3	M 4	M 5	M 6
ϕ_{11}	1	1	1	1	1	1	1,2
ϕ_{12}	1,4	1	0	1,4	0	1,4	1,2
ϕ_{21}	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3	1,2,3,4
ϕ_{22}	1,3	1,3	1,3	0	0	1,3	1,3
DoF		1	2	1	2	1	1
log(L)	-116.70	-118.05	-119.54	-119.87	-122.70	-120.93	-116.651
LR		2.70*	5.68*	8.33**	12.00**	28.46**	.12

Note: * (**) means statistically significant at 10% (5%) level.

Table 6.6a Statistics of Fitting One-dimensional Autoregressive E and T Processes for Sweden (1968-1985)

The order of lags	E Process FPE	E Process SC	T Process FPE	T Process SC
1	21.757	3.178	219.51	5.489
2	20.160	3.149	235.38	5.606
3	22.480	3.303	251.28	5.717
4	24.032	3.412	281.21	5.871

Table 6.6b The Optimum Lags of the Manipulated Variable and the FPE and SC of the Controlled Variable for Sweden (1968-1985)

Controlled variable	Manipulated variable	Lags	FPE	SC	Max Chi2
E(2)	T	None	20.160	3.149	
		3	12.606	2.725	11.13**
		1,3	13.053	2.801	1.14
		1,2,3	12.656	2.808	1.99
		1,2,3,4	13.384	2.897	0.82
T(1)	E	None	219.51	5.489	
		1	205.02	5.468	2.99
		1,3	209.31	5.534	1.39
		1,3,4	233.20	5.684	0.14
		1,2,3,4	263.14	5.843	0.02

Notes: ** means statistically significant at 10% level.

Table 6.6c Autoregressive Estimates of E and T Processes for Sweden (1968-1985)

	FIML Estimates		OLS Estimates	
Variable	Coefficient	t-statistic	Coefficient	t-statistic
E Process				
E1	.642	4.064	.643	4.137
E2	-.493	-3.442	-.502	-3.342
T3	.230	4.656	.227	3.337
Std.err.	2.833		3.211	
T Process				
T1	-.498	-1.712	-.569	-1.828
E1	.978	.805	1.036	1.728
Std.err.	12.122		13.256	

Table 6.6d Likelihood Ratio Tests Against Lower and Higher Order Autoregressive Processes for Sweden

		Lower Order				Higher Order			
	Base	M 1	M 2	M 3	M 4	M 5	M 6	M 7	M 8
ϕ_{11}	1,2	1,2	1,2	1,2	1	1,2,3	1,2	1,2	1,2
ϕ_{12}	3	0	3	0	3	3	3	1,3	3
ϕ_{21}	1	1	1	1	1	1	1,2	1	1
ϕ_{22}	1	1	0	0	1	1	1	1	1,2
DoF		1	1	2	1	1	1	1	1
log(L)	-114.3	-119.85	-115.75	-121.34	-119.62	-113.29	-113.30	-113.57	-114.23
LR		11.06**	2.86*	14.03**	10.58**	2.28	2.05	1.52	.86

Note: * (**) means statistically significant at 10% (5%) level.

Table 6.7a Statistics of Fitting One-dimensional Autoregressive E and T Processes for the U.S. (1961-1987)

The order of lags	E Process FPE	E Process SC	T Process FPE	T Process SC
1	73.273	4.390	637.72	6.554
2	54.629	4.144	642.34	6.608
3	58.132	4.252	673.68	6.703
4	58.918	4.312	721.00	6.816

Table 6.7b The Optimum Lags of the Manipulated Variable and the FPE and SC of the Controlled Variable for the U.S. (1961-1987)

Controlled variable	Manipulated variable	Lags	FPE	SC	Max Chi2
E(2)	T	None	78.958	4.512	
		4	47.785	4.056	10.09**
		2,4	50.624	4.160	0.40
		2,3,4	53.846	4.267	0.32
		1,2,3,4	55.844	4.346	0.83
T(1)	E	None	637.72	6.554	
		1	585.77	6.516	4.16*
		1,4	590.45	6.571	1.60
		1,2,4	628.35	6.679	0.31
		1,2,3,4	670.31	6.788	0.27

Note: * (**) means statistically significant at 20% (10%) level.

Table 6.7c Autoregressive Estimates of E and T Processes for the U.S. (1961-1987)

	FIML Estimates		OLS Estimates	
Variable	Coefficient	t-statistic	Coefficient	t-statistic
E Process				
E1	-.381	-1.706	-.335	-1.698
E2	-.331	-2.106	-.349	-1.894
T4	.125	2.381	.087	1.908
Std.err.	6.046		6.451	
T Process				
T1	.211	1.538	.288	1.607
E1	1.396	2.519	1.351	2.039
Std.err.	21.732		22.961	

Table 6.7d Likelihood Ratio Tests Against Lower and Higher Order Autoregressive Processes for the U.S.

		Lower Order				Higher Order	
	Base	M 1	M 2	M 3	M 4	M 5	M 6
ϕ_{11}	2	2	2	1	2	3	2
ϕ_{12}	4	4	0	4	0	4	4
ϕ_{21}	1	1	1	1	1	1	2
ϕ_{22}	1	0	1	1	0	1	1
DoF		1	1	1	2	1	1
log(L)	-203.45	-205.75	-207.96	-205.70	-210.10	-203.14	-203.37
LR		4.61**	9.02**	4.49**	13.30**	.63	.16

Note: ** means statistically significant at 5% level.

6.4. Conclusions

In this Chapter, causality relations between the machine tool industry and the engineering industries were tested by using Granger's concept of 'causality' and the approach of time series analysis. These tests clearly show that bidirectional causality relations exist, and that the 'feedback' from the machine tool industry to the engineering industries takes more time.

Some caveats of this method should be emphasized before drawing strong conclusions about these tests. First, the causality tests as used in this study can not detect 'instantaneous causality'. Fortunately this deficiency of the test method does not create a problem in our case, since causality relations were detected for three countries. Second, the most important conceptual weakness of causality tests based on Granger's definition is the fact that this approach basically tests 'predictability' of one time series in terms of the second series. Granger himself admits that '[i]t is doubtful that philosophers would completely accept [Granger-causality] definition, and possibly *cause* is too strong a term, or one too emotionally laden, to be used. A better term might be *temporally related*, but since cause is such a simple term we shall continue to use it' (Granger and Newbold, 1977: 225). The concept of 'causality', of course, includes 'predictability', but the inverse is not true. However, in spite of this problem, these tests based on Granger's definition of 'causality' are very informative, and can be accepted as 'exploratory data analysis'.

In the preceding section, it was found that there is not any significant decline in the magnitude of the negative effects of deterioration in the U.S. machine tool industry on the international competitiveness of the engineering industries during the period of 1979-1984. This result may show that the existence of domestic technological capabilities in the manufacturing of machine tools may be an important factor for the development of domestic engineering industries. The results of the Granger-causality tests carried out in this chapter are in accordance with this interpretation, since they cover a long time period for four different countries. Although the Granger-causality tests do not explain or suggest any structure in which economic variables are connected to each other in a specific way, they may, nevertheless, be considered as a support for the existence of bidirectional causality relationships between the development of domestic machine tool and engineering industries.

CHAPTER 7

SYNOPSIS

There is an intense debate on the role of the machine tool industry in industrial development, the effects of new flexible manufacturing technologies, and the implications of a weak domestic machine tool industry for the international competitiveness of domestic engineering industries. Although the debate continues over the role of a domestic industry, there is no empirical evidence shown to support or reject various hypotheses on those subjects. This study is aimed primarily at clarifying and statistically testing the relationships between the machine tool industry and the engineering industries.

For implementing these goals, a conceptual framework in which the basic characteristics of the design and development process of machine tools, and the specific characteristics of machine tool user and producers relationships can be analyzed was developed. From this framework, two testable hypotheses were formed. The first hypothesis is related to the engineering industry's responses to 'external' shocks in the field of machine tool technology. The constituent parts of this hypothesis can be summarized as follows (Chapter 2).

P1) Machine tool users tend to purchase machine tools from those producers that are 'proven', that have similar approaches to metalworking (proximity in manufacturing philosophies), and that produce machine tools compatible with currently used machines. These decision rules (routines) in the procurement of machine tools by user firms may create an inertia in the relationships between users and producers. Selection of *new* machine tool suppliers is a risky, costly, and time-consuming process for machine tool users.

P2) Technological capabilities in the design and manufacturing of machine tools are created by a cumulative process and they are not easily transferable. In other words, the technological position of machine tool firms can be brought about only slowly and their current position is determined by their production history.

P3) Recent changes in machine tool technology are towards flexible automation via NC technology. This trend is intensified by i) the increasing importance of control operations in total machine time in the majority of metalworking processes, ii) the deepened need for flexibility in the engineering industries as a result of economic instability and increased international competitiveness in the last decades, and iii) (exogenous) developments in electronics technology. Foreign, especially Japanese, producers have a significant lead in the manufacturing of flexible automation equipment.

P4) U.S. machine tool producers have excelled relatively in the manufacturing of mass production equipment since their major customers, U.S. engineering firms, have emphasized mass production of interchangeable parts (the so-called 'American System of Manufacturing') for a long time.

P5) Recent emphasis on flexible automation (P3) has been catastrophic for the U.S. machine tool producers, since they have faced serious problems in adjusting their solid technological position in the manufacturing of mass production equipment towards the manufacturing of flexible automation equipment (P2 and P4). The U.S. engineering industries may be negatively affected by the development of these new technologies by foreign firms because they tend to be supplied by the domestic machine tool producers for some time even though their products may be inferior to those of the foreign producers (P1).

Prior to the empirical analysis of various propositions that compose this hypothesis (P5), the correspondence between machine tool types and manufacturing systems, and the distribution of manufacturing systems across engineering industries were determined in Chapter 3, because all available data are based on machine tool types. In this chapter, major manufacturing systems and their characteristics were found on the basis of U.S. machine tool stock data, as interpreted through factor analysis. The results show a clear pattern of manufacturing systems defined by specific types of machine tools, and they are robust with respect to the factor extraction and rotation methods. Factor analysis was used primarily as an exploratory tool in this stage. Its results (factor scores representing manufacturing systems) are also used to test the hypothesis that flexibility of manufacturing technologies affects the international competitiveness of the engineering industries.

In Chapter 4, changes in the structure of machine tool production toward flexible automation were analyzed on the basis of machine tool production data using the correspondence between machine tool types and manufacturing systems as determined in Chapter 3. It was found that those systems that are based on flexible technologies have been increasing their shares by replacing conventional machine tools and, to some extent, mass production equipment, as shown in the increasing share of NC machine tools in total machine tool production and in the share of their respective operation groups. U.S. machine tool producers seem to be relatively more competitive (although they are losing their position in this field, too) in the manufacturing of mass production machinery as reflected in the relatively higher net export ratios for those types of machine tools.

There are two possible extensions for further research in this subject. First, the machine tool stock data on which factor analysis was based are available only for 1983. Therefore, a direct comparison of relative changes in the use of manufacturing systems could not be accomplished. The results of the latest survey covering 1988 will be available in November 1989. Thus, direct comparisons can be done using data for both years. In this way, changes in each industry can also be obtained. Second, detailed analyses were carried out only for the U.S. machine tool industry. Similar analyses for other countries will be useful for comparison of various country responses.

In Chapter 5, the inertia hypothesis was tested using the effects of U.S. direct foreign investment in the engineering industries of foreign countries on the machine tool imports by those countries. In a regression model, it was found that the DFI in the engineering industries have a positive and statistically significant effect on machine tool imports from the U.S. This result was interpreted as support for the inertia hypothesis that implies that U.S.-owned engineering companies, following the tendency to purchase from the 'proved' producers (i.e., parent company's machine tool vendors) may prefer to import from the U.S. This result can be considered an indirect support of this hypothesis because the data used were at the macro-level. Thus, an extension of this test can be done by using micro, firm-level data.

The effects of deterioration in the U.S. machine tool industry on the international competitiveness of the engineering industries were tested in Chapter 5. For this purpose, an index, EFFMT, was calculated to be used as a proxy for these effects. It was found that the U.S. engineering industries were negatively affected during the early-1980s as a result of the decline in the U.S. machine tool industry. The adoption by machine tool users of new connections with leading-edge foreign producers may lessen the effects of diminishing technological capabilities of domestic producers. But the level of these effects did not change from 1979 to 1984 as shown in the regression results. Two factors may be responsible for this result: i) the slow or lagged nature of the adoption process that did not show its effects in this period, and ii) the lack of proximity to advanced machine tool producers which neutralized the benefits from any technological connections that may have been established. This factor, of course, is related to the following hypothesis on causality relations.

The second primary hypothesis analyzed in this study is on the causality relations between the development of a domestic machine tool industry and the development of engineering industries. It was suggested in Chapter 2 that the development of a domestic machine tool industry may be beneficial to domestic users via three channels: i) it reduces transaction costs involved in transportation and communications between users and producers, ii) it creates intra-industry and inter-industry external economies by educating the labor force, diffusing new metalworking technologies, etc., and iii) it facilitates better coordination of economic activities as a result of closer producer/user interactions. Note that the key source of these potential benefits is better information flows within regional boundaries. While there is some anecdotal evidence to support these arguments, it has not been well documented empirically. Therefore, the causality relation between the development of domestic machine tool and engineering industries were tested in Chapter 6 using the concept of Granger-causality without any explicit treatment of the sources of these effects. The results of these tests showed that there are bidirectional causality relations between these industries. This result is strong in the cases of Japan, Sweden, and the U.S.; it is also valid for West Germany though with some qualifications.

The major limitation of the Granger-causality test based on the approach of time series analysis is that it does not envisage any linkages between economic variables and is silent about the sources of causality effects. Therefore, a major extension of this research should be directed toward building a complete econometric model in which causality relations are explicitly formulated. Such a model would obviously improve our understanding of causality relations between the development of a country's machine tool industry and its engineering industries.

APPENDIX

CAUSALITY TESTS AND GRANGER CAUSALITY

The concept of causality has been widely used but not clearly and consistently defined in various scientific fields. In most definitions, 'cause' means any event or condition that brings about a result. An extensively used definition of causality in economics is Feigl's in which causation is defined in terms of 'predictability according to a law or set of laws' (for a detailed discussion of this concept, see Zellner, 1979 and 1988). Another widely used definition in economics was introducer by C.W.J. Granger (1969), who built on earlier work by Wiener. According to this definition, known also as Wiener-Granger causality, a time series Y 'causes' another time series X (Y => X), if we are better able to predict current X, X_t, using all available information than if the information apart from the *past* values of Y had been used. Instantaneous causality occurs when the current value of Y, Y_t, is better predicted if the current value of X is included in prediction than if it is not.

Both Feigl-Zellner and Wiener-Granger definitions are based on 'predictability' criteria whereas the former definition stresses the importance of 'laws' that provide understanding and explanation of (causality) relations under investigation. Although both of these definitions may be seen too restrictive or too broad by some philosophers of science, this subject will not be discussed here.

There are two methodological approaches employed in efforts to test causality relations in Economics: time series analysis and the more classical econometric approach based mainly on the regression analysis. In the classical econometric approach, a model of relationships between economic phenomena derived from the theory is formed and causal relations are tested by the estimation of the model. In time series analysis, causality relations between two or more time series of economic variables can be tested by, for example, using the Granger definition and methods derived thereof. These two approaches, time series analysis and classical econometric analysis, employ implicitly or explicitly Granger and Feigl-Zellner definitions, respectively.

Time series analysis, and, therefore, Granger causality tests, have been criticized because of the lack of any theoretical framework in which causality relations connecting economic variables (time series) are explained. For example, Zellner argues that Granger tests can not establish any causal relation (predictability according to a *law*) on purely statistical grounds, since these tests, by definition, do not envisage any economic law in their structure and predictions. He strongly recommends the use of 'sophisticatedly simple' models if it is difficult to build a theoretical framework. 'If there are no effective models or theories available to explain a phenomenon, for example the variation of stock prices, a sophisticatedly simple initial hypothesis or model is that "all variation is random unless shown otherwise", a suggestion put forward by [H.] Jeffreys. This stance has proven to be very fruitful in stock market research' (Zellner, 1988: 14).

The lack of any theoretical framework in Granger tests is one of the advantages, not disadvantages, of this method, according to time series analysists. It is argued that any theoretical framework restricts the range of possible alternatives, arbitrarily depending on researchers' a priori choices. The classical econometric approach tests causality relations built into econometric models and, in addition to these, a priori restrictions imposed on them by the framework. That is, causality relations in econometric models can only be tested jointly with some (overidentifying) restrictions. 'To solve this dilemma, the tests based on the Granger definition are available. They exploit the fact that to test exogeneity, one needs no more identifying restrictions than that some of supposedly exogenous variables are known not to enter the reduced form' (Sims, 1979: 107).

In brief, the discussion of these two approaches suggests that it may be more informative to employ econometric models when there is strong a priori 'belief' that the model closely reflects economic relations. If it is difficult to build a model, even a sophisticatedly simple one, Granger tests may be helpful, at least, as an 'exploratory' data analytic exercise.

Granger's definition of causality, in the above summarized form, is too broad to be operational. Hence, some assumptions on the structure of processes and certain criteria on prediction comparisons are required.

Granger assumes that the time series are stationary, predictions are linear least-squares projections, and variance is the criterion for prediction comparison. Of course, these assumptions can be modified without changing the definition (e.g., mean-square error criterion can be used instead of variance criterion, etc.).

Consider a stationary stochastic process A_t. Let A^*_t represent the set of *past* values of A_t, A^{**}_t the set of past and present values of A_t, and $A^*(k)$ the lagged-set of A_t ($A^*(k) = \{A_{t-j}, j = k, k+1,...,\infty\}$). An unbiased least squares predictor of A_t using the set of values B_t is denoted by $P_t(A|B)$, the predictive error $\epsilon_t(A|B) = A_t - P_t(A|B)$, and the variance of $\epsilon_t(A|B)$ by $\sigma^2(A|B)$. Then Granger (1969) defines 'causality', 'feedback', 'instantaneous causality', and 'causality lag' as follows.

> Let U_t be all the information in the universe accumulated since time t-1 and let $U_t - Y_t$ denote all this information *apart* from the specified series Y_t. We then have the following definitions.
>
> Definition 1: *Causality.* If $\sigma^2(X|U) < \sigma^2(X|U^*-Y^*)$, we say that Y is causing X, denoted by $Y_t => X_t$. We say that Y_t is causing X_t if we are better able to predict X_t using all available information than if the information apart from Y_t had been used.
>
> Definition 2: *Feedback.* If
> $\sigma^2 (X|U^*) < \sigma^2(X|U^*-Y^*)$,
> $\sigma^2 (Y|U^*) < \sigma^2(Y|U^*-X^*)$,
> We say that feedback is occurring, which is denoted $Y_t <=> X_t$, i.e., feedback is said to occur when X_t is causing Y_t and also Y_t is causing X_t.
>
> Definition 3: *Instantaneous Causality.* If $\sigma^2(X|U^*,Y^{**}) < \sigma^2(X|U^*)$, we say that instantaneous causality $Y_t <=> X_t$ is

occurring. In other words, the current value of X_t is better 'predicted' if the present value of Y_t is included in the 'prediction' than if it is not.

Definition 4. *Causality Lag.* If $Y_t => X_t$, we define the (integer) causality lag *m* to be the least value of *k* such that $\sigma^2(X|U\text{-}Y(k)) < \sigma^2(X|U\text{-}Y(k+1))$. Thus, knowing the values of Y_{t-j}, $j = 0,1,\ldots,m\text{-}1$, will be of no help in improving the prediction of X_t.

Note that, in Granger's definition, the concept of 'causality' does not include instantaneous causality which is defined separately. 'Instantaneous causality' is a statistical concept whose existence is partly determined by the intervals of data recording. Thus, instantaneous causality may occur when annual data are used but not when monthly data are used. Moreover, as shown by Pierce and Haugh (1979), Y_t causes X_t instantaneously if and only if X_t causes Y_t instantaneously. That is, instantaneous causality is always bidirectional.

Assume that the relevant information set can be constrained into two time series X_t and Y_t under consideration and a bivariate dynamic simultaneous equations model containing these series can be represented in autoregressive (AR) form as follows (Wu, 1983).

$$[A.1] \quad \begin{vmatrix} A(L) & B(L) \\ C(L) & D(L) \end{vmatrix} * \begin{vmatrix} X_t \\ Y_t \end{vmatrix} = \begin{vmatrix} u_t \\ v_t \end{vmatrix} ,$$

where L is the lag operator defined by $L^jX_t = X_{t-j}$, $A(L) = A_0L^0 + A_1L^1 + A_2L^2 + \ldots$, and A_j are scalar constants. Other operators B(L), C(L), and D(L) are similarly defined. It is assumed that (u_t, v_t) are independently normally distributed over t with mean zero and a positive definite covariance matrix Σ. It is further assumed that the model is stable.

In Equation A.1, Y_t does not cause X_t in Granger's sense if and only if $B(L) = 0$ or $B(L)$ is proportional to $D(L)$. For higher order lag structures (i.e., in dynamic models), the latter condition is unlikely to occur. Thus, it can plausibly be assumed a priori that $B(L)$ is not proportional to $D(L)$ unless $B(L) = 0$. In this case, causality can be defined only by the condition $B(L)=0$.

In causality tests, the reduced form of the equations is used. The reduced form of Equation A.1. can be written as follows.

$$[A.2] \quad \begin{vmatrix} X_t \\ Y_t \end{vmatrix} = \begin{vmatrix} a(L) & b(L) \\ c(L) & c(L) \end{vmatrix} * \begin{vmatrix} X_t \\ Y_t \end{vmatrix} = \begin{vmatrix} u^*_t \\ v^*_t \end{vmatrix} \quad , \quad \text{where}$$

$$[A.3] \quad \begin{vmatrix} -1 & B_0 \\ C_0 & -1 \end{vmatrix} * \begin{vmatrix} a(L) & b(L) \\ c(L) & d(L) \end{vmatrix} = - \begin{vmatrix} A^*(L) & B^*(L) \\ C^*(L) & D^*(L) \end{vmatrix} \quad , \quad \text{and}$$

$A^*(L) = A(L) - A_0$. The covariance matrix of the reduced form disturbances (u^*_t, v^*_t), Ω, is defined by $T\Omega T' = \Sigma$, where

$$T = \begin{vmatrix} -1 & B_0 \\ C_0 & -1 \end{vmatrix}.$$

In reduced form, Y_t does not cause X_t iff $b(L) = 0$ in Equation A.2.

The least squares estimates of each equation in [A.2] is consistent and asymptotically normally distributed for contemporaneously correlated white noise residuals (u^*, v^*) (Hsiao, 1979a: 326). Therefore, causality running from Y_t to X_t can be verified by finding OLS estimates of the first equation in [A.2], and by testing $b(L) = 0$. Recall that this test does not cover instantaneous causality. It can cope only with the problem of 'causality' in the Granger sense. Thus, the null hypothesis ($Y_t \neq> X_t$) tested is necessary but not sufficient to imply that Y_t does not cause X_t in any way including instantaneous causality. Therefore, when the null hypothesis is rejected, there is Granger causality relation for sure, but otherwise, instantaneous causality may still exist. To test instantaneous causality, the structural parameters of Equation A.1 are required. Since the structural parameters can be estimated only if they can be uniquely determined from the reduced form coefficients, the instantaneous causality hypothesis may not be testable depending on the form of structural equations. This is one of the major criticisms of causality tests based on Granger's definition (Jacobs, Leamer and Ward, 1979).

The existence of instantaneous causality may not be problematic in two cases. First, as explained above, when the null hypothesis is rejected, i.e., when $Y_t => X_t$, its existence may not be a major concern. Second, when the expected time period of causality relation is longer than the periodicity of data used, instantaneous causality may be assumed to be nonexistent a priori. For example, quarterly and/or monthly data may be sufficient for such an assumption for many economic time series.

The test method outlined above is usually called a 'direct Granger test', or simply 'Granger test' because the restriction b(L) = 0 in Equation A.2 stems directly from the definition. Another practical Granger causality test technique has been developed by Sims (1972). Sims' test is based on the fact that if Y_t does not cause X_t in Granger's sense, the least squares estimates of Y_t, given the observations of future and past values of X_t, is identical to the estimate of Y_t, given the observations of only past values of X_t. In other words, if all coefficients of future values of X_t, X_{t+s}, $s = 1,2,...,m$, in the following equation are not significantly different from zero, there is not any Granger causality running from Y_t to X_t.

[A.4] $Y_t = \Sigma^m_{s=1} a_i X_{t+s} + \Sigma^n_{s=0} a_i X_{t-s} + u_t$.

Although Sims' test and the direct Granger test are equivalent conceptually and both of them are asymptotically valid, the outcomes of Monte Carlo experiments show that the small sample performance of the direct Granger test is superior to that of the Sims test (Guilkey and Salemi, 1982; Geweke, Meese and Dent, 1983). Therefore in this study, the direct Granger test is used.

There are two crucial steps in the application of Granger tests that directly affect the outcome: i) selecting the order of autoregressive processes a(L), b(L), c(L), and d(L) in Equation A.2, and ii) testing linear restrictions b(L) = 0 (or c(L) = 0) for causality running from Y_t (X_t) to X_t (Y_t). Some researchers apply ad hoc approaches, such as using a priori a few arbitrary lag structures. But, as Thornton and Batten (1985: 165) stated, 'these approaches ignore the prominent role that model specification should play in causality testing'. Different lag structures selected a priori may lead to contradictions in test results. To circumvent this problem of subjectivity, some statistical criteria for determining the lag structure have been developed. These statistical criteria incorporate an explicit information criterion in model selection to trade off the divergent considerations of bias associated with a parsimonious parameterization against the inefficiency associated with overparameterization. 'Because various criteria give different weights to the bias/efficiency trade-off, they can select quite different lag structures' (Thornton and Batten, 1985: 166).

A widely used statistical criterion in lag-length selection is Akaike's final prediction error (FPE) criterion. The FPE is defined as the (asymptotic) mean square prediction error. Thus, the FPE criterion selects the lag-length so that the mean square prediction error is minimized. There are some other criteria (Sawa's Bayesian information criterion, Akaike's information criterion, etc.) which are asymptotically equivalent to the FPE criterion. Note that these criteria are asymptotically inefficient in the sense that for a finite order AR process, they asymptotically overestimate the order with positive probability. In other words, the probability of selecting a model which is too small vanishes asymptotically but the probability of overfitting does not vanish (Geweke and Meese, 1981: 63). Asymptotically efficient criteria have also been developed. Schwarz's Bayesian information criterion (SC), and Geweke and Meese's Bayesian estimation criterion function (BEC) are among the asymptotically efficient criteria which lead to selection of the proper model with unit probability asymptotically (Geweke and Meese, 1981: 64-65).

In Monte Carlo experiments, the FPE criterion (and other related criteria) tend to overfit the lag-length of the model, whereas the SC and BEC criteria that place greater penalty on large parameterization have a tendency to underfit in small samples. Therefore, in the causality tests used in the Chapter 6, both the FPE and SC criteria will be applied to conform whether models selected by different statistical criteria yield contradictory results.

The second critical stage in modelling causality relations is to test linear restrictions. Some asymptotically equivalent test statistics can be used for this purpose (namely, the Wald, likelihood ratio, and LaGrange-multiplier tests). But a method proposed by Hsiao determines simultaneously the order of AR process and tests the causality relationships. The method can be summarized as follows (Hsiao, 1979: 327-328).

(1) Determine the order of the one-dimensional autoregressive process, say *y*, using the FPE criterion.
(2) Take *y* as the only output of the system and assume *x* as the manipulated variable which controls the outcome of *y*. Use the FPE criterion to determine the lag order of *x*, assuming the order of the lag operator of *y* to be one specified in Step 1.
(3) Compare the smallest FPE's of Step 1 and 2. If the former is greater than the latter, we say $x => y$, and the optimal model for predicting *y* is the one, including say *m* lagged *y* and *n* lagged *x*.

If the converse is true, we say $x \nRightarrow y$ (at orders *m*, *n*), and a one-dimensional autoregressive representation for *y* is tentatively used.

(4) Repeat Step 1 to 3 for the *x* process, treating *y* as the manipulated variable.

(5) Combine all single equation specifications in order to identify the system. Since the sequential procedure may bias the joint nature of the process and the single equation approach is equivalent to ignoring the effect of possible correlations within the components of the innovation, diagnostic checks are recommended to examine the adequacy of the model specification. These tests can be carried out by treating the specification of the system as the maintained hypothesis and performing likelihood ratio tests by deliberately over- and under-fitting the model.

In our tests, this sequential procedure was repeated by substituting the SC criterion for the FPE criterion. Moreover, as shown in the Chapter 7, a ‘causality lag’ may be expected in the relations between the machine tool industry and the engineering industries. The subset autoregression method suggested by McClave (1978) was applied to find any lagged structure in the causality relations after Step 2 for each test.

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