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THE WORLD MACHINE-TOOL INDUSTRY

Background paper*

Prepared by

the UNIDO Secretariat

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CHAPTER I: INTRODUCTION TO THE MACHINE-TOOL INDUSTRY

1 A strategic industry

The machine-tool industry is a small manufacturing sector with worldwide sales of US$ 42 billion in 1989. It is a rather slow growing sector: its turnover was fifteen per cent that of the electronics industry in 1974 and only nine per cent in 1989. (Table 1)

Table 1: World machine tool production in perspective
(in US$ billions)

Industry	1974	1980	1986	1988	1989
Machine-tools	13	26	29	38	42
Electronics	87	196	346	430	445

Sources: American Machinist and
Yearbook of Word Electronics Data

Despite its relatively small size, the machine-tool industry is widely regarded as a strategic industry. Machine tools have been described as "*mother machines*", that is, capital goods used to produce other capital goods.[1] Their range of application extends from the manufacture of light consumer products to that of capital goods like gas trubines and airplanes; these disparate industries depend or converge upon the same tools, machines or processes for their manufacture. The main importance of the machine-tool industry lies in its strategic role in the learning process associated with industrialization. "*This role is a dual one: (i) new skills and techniques were developed or perfected in the machine-tool industry in response to the demand of specific customers; and (ii) once they were acquired, the machine-tool industry was the main transmission centre for the transfer of new skills and techniques to the entire machine-using sector of the economy*".[2] The machine-tool industry is the supplier of

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(1) An expression coined by J. Nehru while inaugurating the Hindustan Machine Tool Factory (R.C. Mascarenhas, Technology transfer and development: India's Hindustan Machine Tool Company, Westview Press, Boulder, Colorado, 1983).

(2) In N. Rosenberg: Perspectives on technology, Cambridge University Press, 1976, page 18.

continuously improving manufacturing technologies which, through machine systems and methods, play a major role in the improvement of overall industrial productivity. It is one of the nodes[3] of across industry diffusion of technological advances. While not necessarily generating a spectacular amount of revolutionary technologies, the machine-tool industry is one of the main obligatory transit points for the direct and indirect diffusion of the effects of such technology into the whole of the capital goods industry. The link between the machine-tool industry and overall manufacturing competitiveness has been recently stressed by the U.S. Commission on Industrial Productivity: "*If American manufacturers must turn to foreign sources for machine tools, they can hardly hope to be leaders in their industries, because overseas competitors will often get the latest advances sooner.*[4]

This strategic role has often explained and justified State involvement. Examples can be traced back to the eighteenth century when, in order to prevent the development of an engineering industry in its American colony, the United Kingdom enacted a legislation to prevent the exports of tools and the emigration of craftsmen to the United States of America.[5] More recently the Domestic Action Plan (DAP) in the U.S.A. was a

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(3) OECD Technology and international competitiveness: an interpretation of the relationships in the machine-tool industry, Directorate for Science, Technology and Industry, Paris, 1984.

(4) Artemis March: The US Machine-Tool Industry and its foreign competitors, in The Working Papers of the MIT Commission on Industrial Productivity, 2 vols Cambridge MIT Press 1989. The director of a machine tool study at General Motors observed: "*If you buy the very best from Japan, it has already been in Toyota Motors for two years, and if you buy from West Germany, it has been with BMW for a year and a half.*" in American Machinist, January 1986.

(5) To circumvent this prohibition Americans paid huge amounts to the technicians to migrate disguised as peasants and laborers with machine sketches sewed in (Machines that Built America).

clear reminder of the strategic importance of the industry.[6] However, apart from the case of centrally planned economies and some developing countries, public enterprises are seldom to be found in this industry. Industrial policies have primarily focused on R&D promotion, preferential public procurement and support for restructuring efforts and modernization plans.

Because of its impact on user industries, the existence of a competitive national machine-tool industry may offer some advantage to the local engineering industry. However, in most cases, there is no clear relationship between the competitiveness of a country's machine-tool industry and the competitiveness of its engineering industries. With the exception of Japan, in most industrialized countries the percentage of machine tools that the engine :ing industry buys locally tends to be small on account of the increasing specialization in the industry.[7] Overall, it appears[8] that the world machine-tool industry acts as a major transmitter of technology to the metal working and engineering sector.

2 Machine tool products classification

While machines are generally dedicated to the manufacturing of a specific product, machine-tools can be defined by their ability to execute a specific process. At the simplest level, machine tools make screws, screwdrivers, nuts and bolts and the

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(6) Initiated by the President of the United States, its objective was to ensure capacity for the most technologically advanced products of the defense industry. The DAP included the Voluntary Restraint Agreement which imposed quota levels to machine-tool imports from Japan, Switzerland and Taiwan, Province of China, and budgetary efforts to develop the next generation of computer controls for machine tools; it included also the prohibition on the Department of Defense to purchase foreign machine tools. US Industrial Outlook 1989/1990, pages 20-21.

(7) Jacobsson: "Intra Industry specialization and development model for the capital goods sector", in Weltwirshaftliches Archiv Band 124 (1988).

(8) Jacobsson S.: "Technological Change in the machine tool industry, implications for industrial policy in developing countries", in New Technologies and global industrialization PPD.141, November 1989, UNIDO.

like; at a more sophisticated level, they make the presses, the casters, and the robots that are used in steel, automotive, and electronics plants. As the tools that make other tools, machine tools are the building blocks of industry.

There are some 3,000 different types of machine tools which differ in the purpose for which they are designed, their size, weight, means of control and price. This large variety has emerged ove the years.(9)

The machine tool industry originated in England in the late eighteen century with the advent of the Industrial Revolution.(10) *"The invention and development of machine tools was an essential part of the industrial revolution. The steam engine, railroad, textile and other manufacturing machinery required machine tools for their progress; it was this demand that stimulated the great progress in the invention of the machine tools that took place... In 1775 the machine tools at the disposal of industry had scarcely advanced beyond those of the Middle Ages: by 1850 the majority of modern machine tools had been invented."*(11)

While day to day innovations have always been important, innovations have notably accelerated during the periods of wars when not only existing machine tools were updated but new ones were invented to meet the exigencies of producing new weapons.

Machine tools can be classified by (i) functions and (ii) means of control.

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(9) For a survey of this history see: Huq M. and Prendergast C. Machine tool production in developing countries, Edinburgh Scottish Academic Press, 1983; in the case of the United States of America, N. Rosenberg : Technological change in the machine tool industry 1840-1910, Journal of Economic History Vol XXIII:4 December 1963.

(10) Before the Industrial Revolution, machine tools had been basically used for weapon production, particularly for musket and cannon barrels.The first power-operated machine tool recorded (1540 A.D.) was a boring machine powered by a water wheel and used to bore muskets and cannon barrels.

(11) K.R. Gilbert: Machine Tools, in A History of Technology, V.4 ed. C.Singer et al. Oxford University Press, 1958.

2.1 Classification by function

The basic distinction is between (i) metalcutting machine tools; and (ii) metalforming machine tools (Box 1).

2.1.1 Metalcutting machine tools

These machines are used to cut away surplus material from a piece of metal in order to produce a part with the desired shape and size. They account for over 80% of machine tools in use. (See Table 3).

Metalcutting can be undertaken by a number of different types of machine tools. The oldest and most widely used, is the lathe, which in the 18th century was commonly known as the engine lathe since it was the first machine driven by Watt's steam engine. While the lathe generates a cyclical contour on the outside of the workpiece, the boring machine generates it on the inside. These machines have been closely associated since the First Industrial Revolution and it was the Wilkinson machine that made the construction of the steam engine possible. Further developments of lathes and boring machines were made in response to the requirements of the textile and railroad industries.

Lighter and more specialized high-speed machine tools were developed during the nineteenth century. Up to the 1860s, mass production of mechanical parts was primarily concentrated in the manufacture of military items. The first extensive use of the turret lathes equipped with a rotating turret that carried as many as eight cutting tools, and of the automatic lathe designed for high volume production, was realized in the United States in the 1840's.(12) The American Civil War (1861-65) encouraged their diffusion and by the 1870's they were widely used in Europe. This technological evolution went along with a change in the production organization, with the introduction of the American system of production which put emphasis on manufacturing as opposed to the English system which was based on making(13); in this new system the essential engineering feature was exact duplication utilizing common features, tools and size gauges.

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(12) The factory of S.Colt built in 1853 was the largest of its kind in the world.
(13) See Chapter III of this document.

Box 1: Main Machine Tools

Metalcutting	Metalforming
Lathes	Presses
Milling Machines	Shearing, nibbling, and notching machines
Drilling Machines	Bending and forming
Boring Machines	Forging and stamping
Grinding Machines	
Machining Centres	
Gear Cutting	
Broaching	
Honning And Lapping	
Physico-chemical Cutting	

Table 2, presents the results of inventories carried out in the United States of America (1988), Japan (1987), the United Kingdom (1987), and France (1986). The largest population of machine tools can be found in the United States of America with the mechanical engineering industries (which includes the machine-tool industry sub-sector) claiming 50 per cent of total installed capacity. The situation is similar in the United Kingdom (43.1 per cent) and France (25.6 per cent). In Japan 34.6 per cent of machine-tools are used by the transport equipment industries while the share of this sector is 16 per cent in the United Kingdom and the United States of America and 24 per cent in France.

Table 2: Stocks of machine-tools in the U.S.A. Japan, United Kingdom, and France

	United States 1988		Japan 1987		United Kingdom 1987		France 1986	
	number	per cent	number	per cent	number	per cent	number	per cent
metal manufactures	320699	13.8	61207	7.7	173497	22.9	203427	33.1
mechanical engineering	1157009	49.7	247231	31.2	326077	43.1	157484	25.6
electrical,electronics	425208	18.3	133175	16.8	105[illegible]	14.0	71111	11.6
transport equipment	378993	16.3	274060	34.6	123733	16.4	147622	24.0
precision equipment	28682	1.2	42994	5.4	27247	3.6	34436	5.6
others	16190	.7	34308	4.3		.0		.0
total	2326781	100.0	792975	100.0	756383	100.0	614080	100.0

Sources: Compiled from national machine-tool inventories published by:
Ministry of Trade and Industry (Japan)
Metal Working Production (United Kingdom)
Bureau d'Informations et de previsions economiques (France)
American Machinist (U.S.A)

During the second half of the nineteen century, the invention of a number of non-military devices such as sewing machines, typewriters, bicycles and finally automobiles, which required much higher degrees of precision and at the same time enjoyed very dynamic demand, made their interchangeability worthwhile if not indispensable.(14) Thus the new production system was quickly adapted from the manufacture of firearms to that of consumer durables.(15)

Due to its high volume production capacity, the milling machine became the first machine-tool to be used on a large scale in engineering production(16). Its demand arose during the American Civil War and latter it became standard equipment in the manufacture of sewing machines. The grinding operation required an enormous amount of time and was a bottleneck in manufacture. Up to the advent of grinding machines, it was said (17) that hand-tools could compete with machine-tools in terms of precision. The universal grinding machine was conceived in 1875 and its diffusion was intimately connected with the growing demand for bicycle (ball bearings) and automobile production. Nothing before the automobile had ever demanded such complicated work in high quantity. The development of the motor vehicle industry had a very significant impact on the machine tool (grinding cam shafts). The discovery of "high speed steel" which greatly improved cutting capacity, made it necessary to re-design the machine tool and led to the Gear cutting machine introduced in 1890 to excavate all the gear teeth simultaneously. Among other metal cutting machine-tools, are sawing and broaching, and polishing machines.

The most widely employed of the non-traditional methods for shaping metal is electric discharge machining which applies the disintegrating effects of an electrical arc to the metal. By means of precise control of the electrical energy input, intricate shapes can be machined to very close tolerances. It is

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(14) David Landes: The unbound Prometheus, technological change and industrial development in Western Europe from 1750 to the present, Cambridge University Press, 1972, pp 308-310.

(15) This was especially the case for turret lathes (multi-tool spindle), and new drilling and boring machines.

(16) Bertrand Gille: Histoire des Techniques. La Pleiade, Gallimard, 1978, page 836.

(17) Bertrand Gille, page 836.

Table 3: Metal cutting machines tools in use

(in units)	United Kingdom 1986	United States 1988
turning	164221	404434
drilling	124011	285006
milling	80250	249106
grinding	79780	434847
sawing and cutting	55308	204654
boring and milling	30546	
screwing,tapping, threading	16823	41483
planing, sharping,slotting	12305	
gear cutting	11659	29509
machining center	10354	53585
honning and lapping	9269	48537
Physico-chemical cutting	8772	19306
unit construction and transfer	4518	48060
broaching	3799	16698
Total metal cutting	611615	1870753

Sources: Compiled from national machine-tool inventories published by:
Metal Working Production (United Kingdom);
American Machinist (U.S.A.)

Table 4: Metal forming machine tools in use

	United Kingdom 1986		Japan 1987
Bending and forming	30466	mechanical presses	69710
hydraulic presses	19872	hydraulic presses	36295
pneumatic presses	5881	bending machines	11714
mechanical power presses	39595	shearing machines	11522
punching and shearing	32658	forging machines	8066
forging and stamping	3479	wireforming machines	6145
miscellaneous	13505	others	44937
Total metal forming	145456	Total metal forming	192038

Sources: Compiled from national machine-tool inventories published by:
Ministry of Trade and Industry (Japan);
Metal Working Production (United Kingdom)

used to manufacture dies and molds and to drill fine holes in high strength alloy steels as well as to produce complex shapes. Electro-chemical machining (ECM) is a cost effective process which eliminates several slow operations and allows the machining of very hard alloys used in industries such as aerospace (for titanium components used in jet engines). The motor industry uses the ECM method for deburring operations on gears and connecting rods. Applications of ultrasonic machining include drilling of non-circular holes for materials such as glass, ceramics and other hard non-conductive materials. Plasma machining offers very high cutting speeds while laser machining has been mainly used in micro-electronics and in precision welding. Electron-beam machining has been limited to the drilling of very fine holes; Skiving is used for the internal finishing of long tubes and deep hole boring for the production of bores in which the length is greater than the diameter.

2.1.2 Metalforming machine tools

These shape metal without the use of a cutting tool, by pressing, forging, bending, shearing, etc. The most widely used metal forming machine tools are presses, which represent nearly one half of this type of machine tool and differ according to their power transmission system (hydraulic, mechanical or pneumatic). Table 4 presents the main categories of metal-forming machine tools in Japan and in the United Kingdom.

2.1.3 Evolution of demand structure

The market shares for metal-cutting (75 per cent of total demand) and metal-forming (25 per cent) machine tools have remained constant over time; however the structure by subgroups has changed.

Figures 1 and 2 show the evolution of world demand in value and in volume in 1980 and 1988.[18] Due to the development of multifunctions machines, demand has slightly decreased in the share of turning, boring and drilling machines. On the other hand significant market gains have been achieved in machining centres

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(18) Adapted from WS Atkins Management Consultants: Strategic study on EC machine tool sector, May 1990, A Report submitted to the Commission of the European Communities.

Figure 1 : World demand by machine type in terms of value

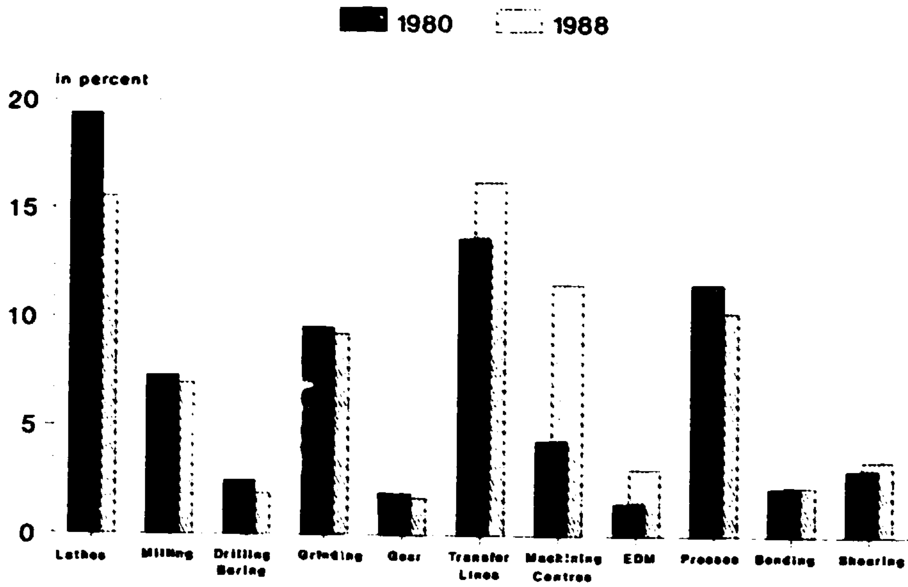
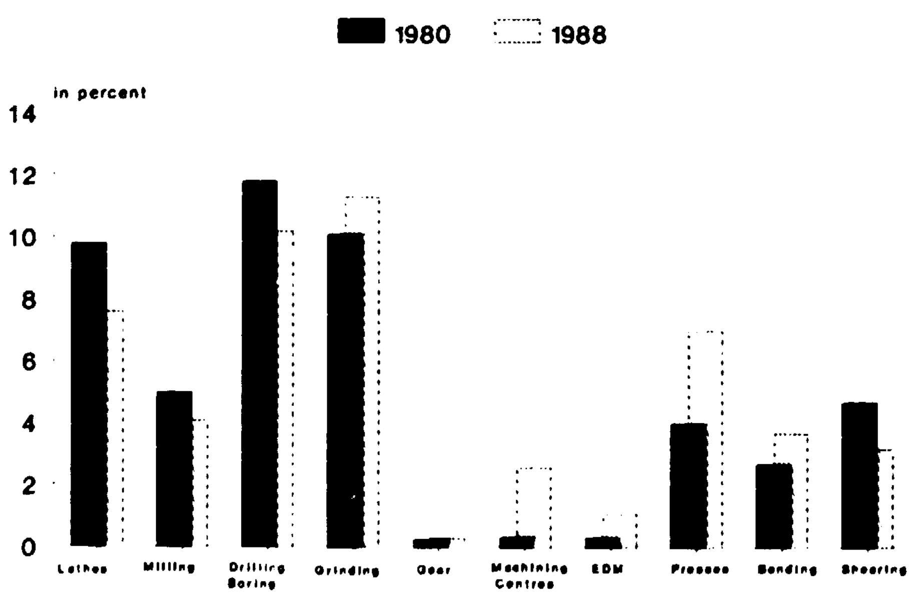


Figure 2 : World demand by machine type in volume



Source: VDW/IFO Institute in EEC'study

and EDMs.

2.2 Classification by means of control

On the basis of means of control, one can distinguish between conventional, automatic and numerical control machine tools.

2.2.1 Conventional machine tools

These machines are controlled by a skilled machinist who studies a blueprint and manually directs the machine based on his knowledge of the machine tool and his interpretation of the drawing. The feedback from the machines is achieved through the hands, ears and eyes of the operator. Throughout the 19th century, technical advances in machining developed by innovative machinists built some intelligence into the machine tools themselves - automatic feeds, stops, mechanical cams etc.- making them partially self-acting. These devices relieved the machinist of certain manual tasks but he retained the control over the operation of the machine. Together with elaborate tooling, fixtures for holding the workpiece in the proper cutting position, and jigs for guiding the path of the cutting tool, less skilled operators were able to use the machines to cut parts after they had been properly set up by a more skilled man. The source of the intelligence, however, was still the skilled machinist on the floor.

Despite the diffusion of NC machines, conventional machine tools represent nine out of ten machine tools installed in the engineering industries of industrialized countries.(19)

2.2.2 Automatic machine tools

With the introduction of new materials in the tools utilized in the early 20th century, it became possible to increase the speed of work and this allowed the introduction of automatic machine tools. Such machines tend to be of special purpose built to carry out a specific sequence of operations making the maximum use of fixtures and tooling.

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(19) See Chapter III of this document.

During the Second World War, automation was one of the major innovations which was developed and further advanced in the 1950s in two different directions: the transfer machine and the numerical control machine tool.

The transfer machine is a combined material- processing and material handling system, with several special machine tools linked together along a transfer line. The workpiece, usually an engine block, is carried on by a conveyor and the transfer machine can perform any of the main metalcutting operations. The transfer lines are well adapted to a Fordist[20] type of factory organization and their main applications are found in the mass production of consumer durables. However they are expensive and their acquisition can only be justified only for very large production runs. Increasing levels of automation meant a need for ever longer production runs with single purpose dedicated machines; this situation was labelled as the "*productivity dilemma*".[21]

Mass production accounts for less than 20% of the total amount of production within the engineering industries. Most of the products are manufactured in small batches.[22] Engineering machine shops thus use multi-purpose machine tools either of low quality/ high productivity (roughing machines) or high quality/low productivity (finishing machines). These manually-operated but very flexible job-shops are characterized by long lead times, large work-in-progress inventories and low machine utilization. The challenge of automating machine tools was to render them self-acting while retaining their versatility. The solution was to develop a mechanism that translated electrical signals into machine motion and a medium on which the information could be stored and from which the signals could be reproduced.

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(20) The concept of Fordism is associated with the organization of mass production of standardized products for a relatively homogeneous market.

(21) W. Albernathy: The productivity dilemma: roadblock to innovation in the automobile industry, John Hopkins University Press, Baltimore, 1978.

(22) In the United States a survey showed that approximately 75 per cent of all machined parts were produced in batches of fewer than 50 units for which capacity utilization was very low.

2.2.3 Numerical control machine tools[23]

The most significant technological development has not been advances in machining per se, but in the control and environment of machine tools. Beginning with NC (See Box 2) these programmable automation technologies have used computers to control the operations of the machines. The first computer controlled machine tool began as a Government-sponsored project carried out at the Massachusetts Institute of Technology Servo-mechanism Laboratory in 1949.[24] Japan's efforts started in the 1950s with the milling machine. The automation involved two separate processes: means of transmitting information from a tape storage medium to the machine to make the tables and cutting tools move as desired; and means of getting the information onto the storage medium. Machine controls could be developed as an extension of gunfire control technology while tape preparation was something new.[25] The first viable solution was "record play back"; it involved a machinist making a part while the motions of the machine under his command were recorded on magnetic tape. After the first piece was made, identical parts could be made by playing back the tape. The second solution, Numerical Control, was based on an entirely different philosophy of manufacturing. The specifications for a part were first expressed in mathematical form. Then a mathematical description of the desired path of the cutting tool was defined from which discrete instructions for the controlled motion of the machine tool were developed. These discrete instructions were then translated into a numerical code and stored on the tape. Thus the choice of the NC solution circumvented the role of the machinist as the source of the intelligence of production.

Whereas in a conventional machine tool the control information is transferred directly to the machine by the operator and then from the machine to the work-piece, involving

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(23) More details concerning technological trend are available in Chapter III of this document.

(24) Development work on NC machine tools began in the United Kingdom in 1950 followed by France and Federal Republic of Germany around 1955.

(25) David F. Noble: Social choice in machine design: the case of the automatically controlled machine tools in The Social Shaping of Technology, edited by Donald Mackenzie and Judy Waschman, Open University Press, 1985.

Box 2: NC: main definitions

(i) Numerical controlled (NC) machining. A manufacturing process controlled in a fixed repetitive way by numerical form of input.

(ii) Computer numerically controlled (CNC). A process where individual machine tools using computer controllers to store and perform operating instructions (e.g. selection of cutting tools, speed and feed rates) with manual loading and supervision. A CNC system is basically an NC system which is flexible because a computer replaces the fixed logical which forms the heart of an NC system and it may thus be programmed to accommodate a variety of changes relevant to the machine type or machine use.

(iii) Direct numerical control (DNC) A DNC system relates to the linking of a number of NC machines to one central computer which in its simplest form may be little more than a sequencer and data bank for storing part-programmes and in its most complex form may be extended to include the house-keeping and control functions of individual machines.

(iv) The machining centre with automatic tool changer indexing is one of the important outgrowths of NC. Traditionally, parts were mobile and moved from one machine tool to the next; in a machining centre, the part is fixed and the tool heads are mobile. Machining centres have automatic tool-changing systems for selecting among the 20 to 100 tools that bore, drill, mill and tap. With a rotary head and tables, a centre can work on many surfaces of a part in a single setup.

(v) Flexible machining system (FMS) is an integrated computer-controlled complex of NC machine tools, automated material and tool handling devices, and automated measuring and testing equipment that, with a minimum of manual intervention and short change-over time, can process any product belonging to certain specified families within its stated capability and according to a predetermined schedule.

(vi) Computer integrated manufacture is a concept of a totally automated factory in which all processes are integrated and controlled by a CAD/CAM system. It consists of software and hardware which together are involved in product design, production planning, production control, production equipment and production process.

thus man and machine limits, (time, rigidity of movement, repetition of the operation) in an NC machine tool such information is translated into a written symbolic language of the microprocessor which will develop the detailed working programmes so that the piece is produced according to design specifications (See Box 3). By simply changing the instructions, the machine can be switched from the production of one part to another. The NC machine tool allows for automatic component-positioning, selection of speed and control of the movement of the tool. In machining centres and turning centres, the right tool is selected and inserted and changed. Flexible manufacturing cells include the automatic handling of the work-pieces while flexible manufacturing systems include transfer of the work-piece from one machine to another.

The choice of the level of automation is a function of the size of the average job and the degree of flexibility required, as can be seen in Figure 3.(26)

Users involved in the production of large quantities of a few different work pieces, will choose special purpose machines (e.g. the transfer line). However, when many workpiece variants are produced in very small amounts, it is most economical to choose conventional machine tools or stand alone NCMT. The pressures changing the needs of special purpose and general purpose machine tool users are converging into the need for a type of production capability which combines the flexibility possible with general purpose machinery and the cost competitiveness of mass production manufacturing equipment. Two different kinds of solution to these needs have been identified: the special purpose FMS such as the versatile transfer line in the automotive industry and the general purpose FMS composed of general purpose Computer Numerical Control (CNC) machines.

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(26) From Hermann Traub Gbmh, Maschinen Fabrik in OECD Technology and international competitiveness: an interpretation of the relationship in machine tool industry, Paris, 1984 page 46.

Box 3: Technological trajectory

The following table shows how over time the various operations have been automated and computer operated through many generations of machines

Manual (M) and automated (A) operations

	manual machining	semi-automated machining	CNC	machining center	FMS
transfer	M	M	M	M	A
loading	M	M	M	M	A
component positioning	M	M	A	A	A
cutting movement	A	A	A	A	A
tool handling	M	A	A	A	A
tool selection	M	M	M	A	A
unloading	M	M	M	M	A

Adapted from Camagni: Il Robot, Lombardo Milan 1987

Figure 3 : From conventional to automatic

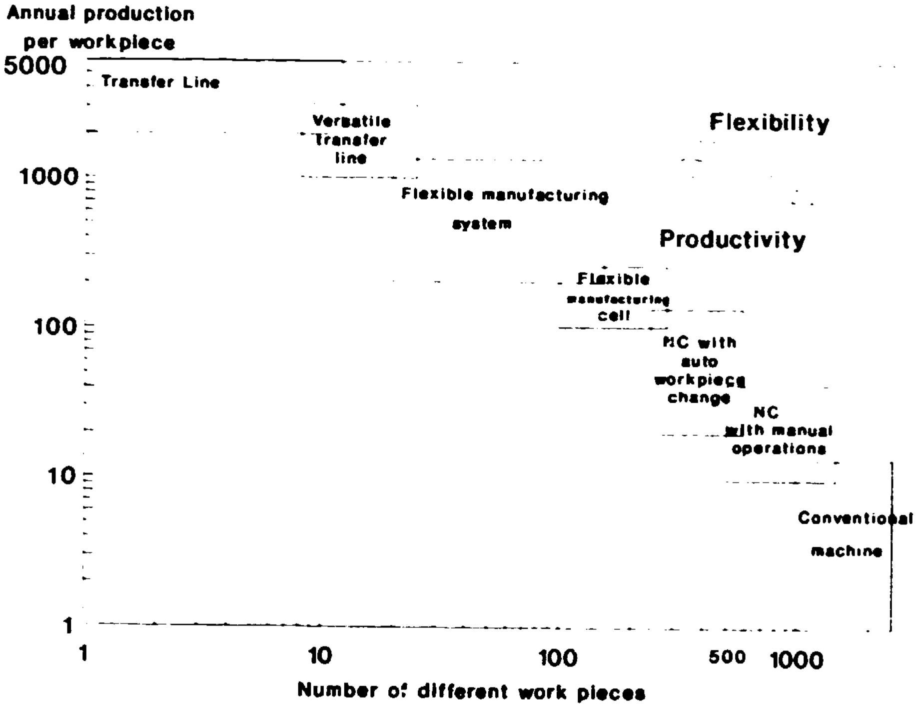
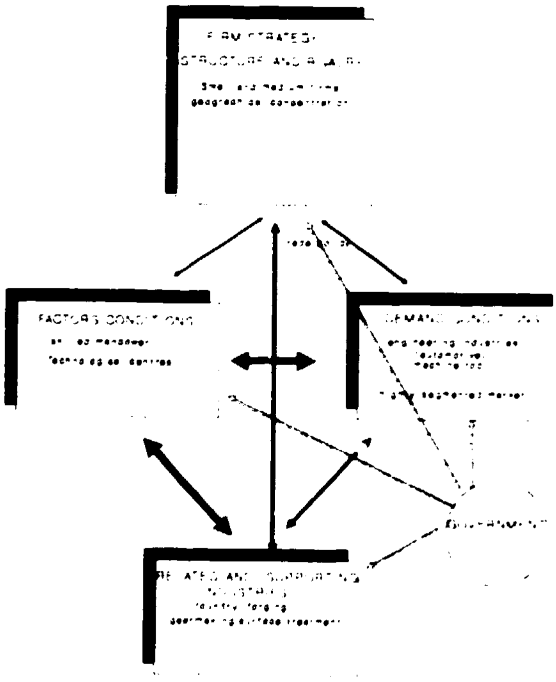


Figure 4: The machine-tool industry diamond



3 Machine-tool industry characteristics

3.1 A mature industry

The machine-tool industry shares some of the characteristics of a mature industry:[27] a slow growing output, a relatively low rate of product innovation and a growing international competition from developing countries.

The industry is based on mature mechanical engineering technologies with a few exceptions (e.g. laser cutting) and technological advancement is evolutionary rather than revolutionary. The level of investment in R&D is on average around 4 to 5 per cent of annual turnover: manufacturers producing highly customized machines undertake large amounts of product development for each machine sold, companies engaged in volume markets have products with relatively short life cycles and try to obtain short term advantage on their competitors through R&D. The industry borrows technological innovations which are developed by other industries (notably electronics). However, and in contrast to other mature industries, the qualifications of required manpower tend to be higher than the average level.

3.2 Economic size

The machine-tool industry's share of GDP is less than 1 per cent in most industrialized countries (Table 5), while its share of manufacturing value added hovers in the 1-3 per cent range. In Japan, machine tool production accounts for 1.2 per cent of the machinery and equipment industry output.

The industry is known for its cyclic nature which results from the multiplier effects of customers orders and cancellations in response to the cycles of their own markets. In periods where production capacities are fully utilized, a 10 per cent variation in the demand for consumer goods may bring about a 40 per cent variation in the demand for capital goods.[28] These cycles have devastating effects on employment. In the U.S.A.

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(27) For a definition of mature industry see OECD: Industry revival through technology, Paris 1987.

(28) B. Real: Technical Change and Economic Policy, the machine tool industry, OECD Paris 1980.

Table 5: Machine tool industry in selected countries

	Value Added in per cent of GDP	number of enterprises	employment in 1988	Output in 1989 US$ millions
Industrialized countries				
Japan	.27	*111	34300	9817
Germany (F.R.G.)	.65	n.a	94000	6859
U.S.A	.06	500	55000	3270
Italy	.28	303	15920	3067
Switzerland	1.00	137		1797
United Kingdom			23000	1597
France			10005	1081
Spain		120	7700	795
Sweden	.23	33	3000	403
Developing countries				
Taiwan, Province of China		210	10000	1016
China, People's Republic		**200		832
Republic of Korea		47	18000	760
Brazil		110		458
India		***319	60000	262
Argentina		36		38

Sources: Statistics from the various manufacturing associations
* Number of members of Japan Machine Tool Builder Associations
** Large enterprises only
*** Number of members of Indian Machine Tool Manufacturers Association

employment in the metalcutting machine-tool industry has oscillated between 45000 and 85000 during the last two decades; less pronounced variations are found in Germany (former FRG) where the industry employs 100,000 workers. This characteristic deters many capable persons to join the industry because of the high probability of periodic layoffs.

3.3 Shifting boundaries: from mechanical to mechatronic

Up to the seventies, the machine-tool industry could clearly be considered as a subsector of the non-electrical machinery industry. The introduction of electronics is changing the "boundaries" of the industry. It has altered the activities of the firms and most of them now engage in substantial buying-in of components, especially electronics control systems, while hiring computer specialists to solve their software problems. An illustration of this change can be found in the list of major machine-tool companies in the world which ranks FANUC (Japan) as the largest in 1988 (Table 7). FANUC is not generally recognized as a machine-tool builder since it concentrates in manufacturing numerical control systems. Software requirements for the NC machine tools have created opportunities for new enterprises to enter the industry.[29]

The machine-tool industry can now be considered as a subsector of the mechatronics sector, which is a combination of mechanical engineering and electronics.[30] In the coming years, subsequent changes will appear through the introduction of new materials replacing steel in mechanical engineering and this could lead to the emergence of new actors in the industry.

3.4 The structure of the industry

3.4.1 Market structure

The market for machine tools is highly segmented and different strategies may coexist within the industry. There are

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(29) They include ALLEN BRADLEY, and also GENERAL ELECTRIC and DIGITAL EQUIPMENT which is working in joint venture with COMAU.

(30) Mick Mc Lean (edited by) Mechatronics, development in Japan and Europe, Frances Pinter (Publishers), London 1983.

about 30 broad categories of machine tools and a series of subcategories related to specific processes. The production technologies and design features differ for each type of products and this has led to specialization in narrow product lines for particular markets. A study by the Boston Consulting Group[31] has identified almost 100 strategically different business segments with many sub-segments (see Box 4):

-At the upper hand, the demand is highly specific and the production is limited to a small number of machines: companies strengths lie in their design team and after-sales support. Overhead expenses are relatively high (45 to 50 per cent of operating expenditure). These exert pressure on profitability during cyclical downturns in demand and offer a premium to flexible medium scale enterprises over large firms.

-Conversely, in volume markets for standards products, price is the most important factor for competition. Companies aim to keep overhead to a minimum. This gives an advantage to larger firms.

3.4.2 Small-scale industries

Machine-tool industry has been an ideal industry for entrepreneurial engineers and machinists who have typically founded small companies based on skill rather than financial strength. The presence of many small firms was made possible by production economies which were obtained from cumulative output of a single model.[32]

Following the acquisition of NC technology by the machine-tool industry, the economical scale of production is changing. Through the introduction of CAD/CAM and the setting up of FMSs, the Japanese have reached significantly higher production volumes than most European and US firms. While, in the case of lathes,

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(31) Boston Consulting Group: Strategic study of the machine-tool industry February 1985. This study carried for the Commission of the European Communities was updated by WS Atkins Management Consultant in association with IFO-Institute (FRG), BIPE (France), Prometeia (Italy) and Imaco (Spain): Strategic study on the EC machine-tool sector, Brussels, May 1990.

(32) C.F. Pratten: "Economies of scale for machine tool-production" in The journal of industrial economics, Vol 19, 1970-1971 pp 148-165.

Box 4: Market differentiation

There does not exist one machine-tool market but several markets which can be categorized according to three criteria:

-degree of specialization of the machine: a conventional lathe has universal application, while some machines are tailor made for one application only
-its production volume: a machining center is well adapted for the production of small series of differentiated products; transfer machines are used in large volume production
-its market potential: producers able to invest heavily wil gain some edge in large markets

The following table shows the main competitive factors for the three main segments, as well as the main suppliers and the forecast for the evolution of world demand for these markets.

	CONVENTIONAL MACHINES	NC MACHINES UNIVERSAL MACHINING CENTER	CONVENTIONAL NC SPECIALIZED
MAIN COMPETITIVE FACTOR	PRICE	PRICE/TECHNOLOGY	TECHNOLOGY
MAIN SUPPLIERS	EAST ASIAN COUNTRIES EASTERN EUROPE	JAPAN	GERMANY (FRG)
SHARE OF WORLD MARKET	16%	36%	48%
MEDIUM TERM GROWTH	slackening	growing	growing

Adapted from P.Fremeaux, R.Touboul: Machine outil 90, les enjeux BIPE Paris 1990 minimum efficient scale of production was estimated to be 400 units per year according to the Boston Consulting Group in 1985. average monthly production of CNC lathes has reached 200 in Japan[33] compared to 40 in most European countries. In the case of the manufacturing of NC machine tools, production volumes are significantly higher in Japan (Box 3).

The dispersion of the industry structure (Table 6)[34] is more pronounced in Europe and the United States. In Italy, according to the results of a comprehensive statistical analysis carried out on a sample of 300 machine tool manufacturers out of 450, 72 per cent of the enterprises employ less than 50 workers. Enterprises with less than 200 workers account for 65 per cent of total employment, 64 per cent of total production and 57.6 per cent of machine tool exports. In Germany (former F R G) the machine-tool industry appears more concentrated than in most industrialized countries. The average size of an enterprise is five times higher than in Italy. More than 70 per cent of the enterprises can be considered as medium enterprises (with up to 250 employees), however they account for 22 per cent of total production, while enterprises with more than 500 workers account for 60 per cent of total output. Many of these enterprises grew from small family firms and although most remain independent, an increasing number are affiliating with industrial conglomerates. The parent firm is often an engineering group that integrates the toolmaker into its total business and makes the investments needed to retain technology leadership.[35]

In Japan, according to the industrial census of 1982, 80 per cent of the enterprises engaged in machine tool production employed less than 50 workers and together these small-scale firms employed 40 per cent of the industry's workforce and produced 21 per cent of the value-added. The productivity of these enterprises, measured by the ratio of value-added to employment, was on average, half of the productivity of the enterprises with more than 100 employees. The Japanese

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(33) For instance output for Hitachi Seiko totals 20 machining centres and 150 large turning centers per month, Machinery and Production, April 1989.

(34) International comparisons are made difficult since national statistics differ in their census' methodologies. In Japan no figures are available for enterprises with less than 50 employees.

(35) MIT Commission on Machine tool working group.

Table 6: Structure of the machine-tool industry

size group	number	%	employee	%	value-added (%)
			Japan 1982		
50-100	517	82.2%	22146	36.4%	22.1%
100-199	60	9.5%	8386	13.8%	15.4%
more than 200	52	8.3%	30390	49.9%	62.5%
TOTAL	629	100.0%	60922	100.0%	100.0%
			Italy		
1-199	290	95.7%	10450	65.6%	63.9%
more than 200	13	4.3%	5470	34.4%	36.1%
TOTAL	303	100.0%	15920	100.0%	100.0%
			Germany (FRG) 1988		
1-100	174	45.8	6674	7.1	
101-250	91	23.9	13536	14.4	
more than 250	115	30.3	73790	78.5	
TOTAL	380	100.0	94000	100.0	
			Republic of Korea 1986		
1 - 100	140	89.7%	2936	49.5%	32.7%
100-199	12	7.7%	1736	29.3%	28.2%
more than 200	4	2.6%	1263	21.3%	39.1%
TOTAL	156	100.0%	5935	100.0%	100.0%

Source: MITI (Japan), UCIMU (Italy)
VDMA (FRG), EPB (Republic of Korea)

Box 5: Economies of scale in NC machine-tool production in Japan

In a survey of 75 producers covering machine cutting and including several relatively small manufacturers of customised machines, the average monthly production was 45 machining centre equivalents. Output by the large volume producers are much larger, typically 200 machining centre equivalent a month and in some cases as much as 400.

One medium-volume company, which has an output of a quarter the size of the largest producers, is currently operating with the following schedule:

-small knee-type milling machine	50/month
-CNC lathes (horizontal, vertical, turret	60/month
-CNC milling	50/month
-Machining centres (horizontal, vertical, and bridge)	50/month

Generaly speaking, the minimum scale of economic operation on a greenfield site is regarded to be 60 machines a month. At these levels Japanese companies have FMS and FMC forms of manufacture. Volume in standardised products also brings the advantages of being able to introduce Just-In-Time and Material- Requirement-Planning (MRP) techniques which have added to production efficiency by improving inventory management.

Extracted from: Strategic study on EC machine-tool sector by WS Atkins Management Consultants, Brussels, May 1990.

machine-tool industry is inclined to subcontract more than European and American manufacturers.

In Eastern European countries, production has usually concentrated in a few large enterprises. In the USSR, the largest firms SESTORETSK metalcutting machine-tool plant employs 4000 workers on one site.[36] In the case of what was formerly the German Democratic Republic, which, in 1988 was the world's seventh largest manufacturer, machine tool production was organized in four "kombinates" which together employed about 80,000 workers.[37] In Czechoslovakia, the companies are large with large product ranges: KOVOSIT, for example, has 5000 workers spread between three factories.[38]

In developing countries, fully integrated machine tool complexes are more usual and production mix is often quite large. When the enterprises were first established, they were confronted with a lack of reliable local sources for such inputs as forging and castings which they chose to integrate. If the capacity (as well as the capacity utilization) is sufficiently high, the cost effectiveness associated with an integrated plant will be acceptable; however if the capacity utilization is low then the plant will not take advantage of the economies of scale in these facilities and will be unable to spread the cost of items such as testing equipment, over a sufficiently large output.

In Brazil, in 1988, there were about 100 machine-tool producers and the five largest accounted for a third of total production: in Argentina, two enterprises accounted for 57 per cent of lathe production, and three out of ten produced 44 per cent of milling machines.[39] In the Republic of Korea, the leading four enterprises produced one fourth of local production in 1986 while in Taiwan, Province of China, most of the production is done by small scale establishments.

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(36) Machinery and production engineering, 5 January 1990.
(37) Economic Commission for Europe Annual Review 1988.
(38) Machinery and production engineering: "Curtain raising build programmes", 1 September 1989.
(39) F. Erber: The electronics complex and industrial automation: a comparison between Argentina and Brazil, UNIDO December 1989.

3.4.3 Main firms

"*If all the employees of the American machine-tool industry were to work for a single company, that company would rank fiftieth in size among American industrial corporations*": by industry standards, large machine-tool producers are not large firms.

Table 7 lists top companies by world-wide sales of machine tools and closely related equipment such as numerical controls; it presents total sales of the company as well as employment.[40] Excluding FANUC (a control manufacturer), the sales of the largest enterprise, YAMAZAKI, represent 1.8 per cent of world sales of machine tools.[41]

Japanese companies dominate the list, they are much larger companies in total than most European or American producers and they gain considerable synergy with other parts of their business. There are some large family-owned businesses (e.g. YAMAZAKI MAZAK) but the majority are either publicly quoted or subsidiaries of larger concerns. The largest company is FANUC which is a world leader for computer numerical controls. AMADA is primarily an engineering and marketing firm whose product lines include several types of machines manufactured abroad. AMADA owns 19 per cent of AMADA SONOIKE and 20 per cent of AMADA WASINO which are manufacturing firms. YAMAZAKI MAZAK ranks highest among purely machine tool building firms. OKUMA MACHINERY WORKS produces its own NC systems for its machines and markets some machines through the AMADA organization; its main lines of production are lathes and machining centers. MORI SEIKO concentrates most of its production on a single highly automated plant in Japan. TOYODA MACHINE is owned by TOYOTA MOTORS; machine tools represent 40% of total sales which are mostly automotive parts. A small proportion of KOMATSU which is primarily a heavy equipment manufacturer is engaged in the manufacturing of heavy presses.

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(40) Such comparisons suffered many complications during the reporting period, inter alia, currency fluctuations and the fact that a company which is primarily a builder was place side-by-side with a firm which is primarily a distributor.

(41) In the case of the electronics industry, the largest entreprise, IBM produce 15 per cent of the world electronics production. Electronics Business, July 1990.

TABLE 7: Top machine-tool companies in the world

in US$ millions		Machine tool sales (in US$ millions)		Total Sales (in US$ millions)	Employment
		1989	1988	1988	
YAMAZAKI MAZAK CORP	Japan	1183	796	796	3000
FANUC LTD	Japan	1079	928	1055	1770
LITTON IND INC	USA	730	600	4863	55000
AMADA CO	Japan	1153	891	1019	1509
CROSS AND TRECKER	USA	456	428		4100 *
COMAU SPA	Italie		380		3500
OKUMA MACHINERY WORKS	Japan	665	551	592	1753
CINCINATI MILACRON	USA	424	361	860	8400 *
MORI SEIKO CP	Japan	635	488		1570
TOYODA MACHINE WORK	Japan	466	418	1045	4367
DECKEL GROUP	FRG		350		
INGERSOLL MILLING	USA	366	345	400	4500
GILDMEISTER	FRG		313		
KOMATSU MTD	Japan	474	398	5580	15801
MAKINO MILLING MACHINERY	Japan	318	270		951
AIDA ENGINEERING	Japan		247		684
AMADA SONOIKE MFG	Japan	390	307		537
TRUMPF GMBH	FRG	340	302		2122
HITACHI SEIKI	Japan	346	275		1237
FUJI MACHINE CO	Japan	392	241		717
TRAUB	FRG		234		
MAHO AG	FRG		232		1799
HUELLER HILL	FRG		223		
THE 600 GROUP	UK		191		
GLEASON WORKS	FRG				3000
SODICK CO	Japan				473
AMCA INTERNATIONAL	Canada				9985
MAZDA MOTOR	Japan				28423
AMADA WASINO MACHINE	Japan		287		404
MITSUBISHI HEAVY	Japan				46690
TOSHIBA MACHINE	Japan	359	256		3525
NIPPEI TOYAMA	Japan				1166
OKUMA & HOWA MACHINERY	Japan				573
CITIZEN WATCH	Japan	338			3348
MANDELLI IND SPA	Italie				710
WEAN UNITED	USA				788
TSUGAMI CORP	Japan				831
OSAKA KIKO	Japan				1032
MONARCH MACHINE TOOL	USA				913
TAKISAWA MACHINE TOOL	Japan				439
OKAMOTO MACHINE TOOL	Japan				544
ENSHU LTD	Japan				969
MET COIL SYSTEM	USA				400
NEWCOR INC	USA				689
BROTHER IND	Japan				5165
HURCO COMPANIES	USA				400
NIIGATA ENGINEERING	Japan				3125
HOWA MACHINERY	Japan				2287
BROWN AND SHARPE MFG	USA				1891

* Including sales by foreign operations

Source: American Machinist August 1990, August 1989

LITTON INDUSTRIES INC. employing 55,000 workers is a diversified conglomerate also comprising LITTON INDUSTRIAL AUTOMATION SYSTEM (machine tool and unit handling systems). CROSS AND TRECKER is also a conglomerate which includes several firms (CROSS, COLONIAL BROACH, DRILLUNIT, CROSS LASALLE, WARNER & SWASEY TURNING, WIEDEMAN, SHEFFIELD, TYCHOWAY, BEARINGS, ROBERS CORP AND ALLIANCE AUTOMATION). Machine tool sales represent only 41 per cent of total sales of CINCINATTI MILACRON (which used to be the world leader in machine tools).

COMAU Spa which is the largest Italian and European company is owned by the FIAT group. In Germany (former FRG) the largest firm is DECKEL followed by TRUMPF, TRAUB, MAHO; a few large engineering groups have machine tool activity (MAN, INDUSTRIE WERKE).

The production of electronic control units for machine tools is a highly concentrated activity. FANUC claims to account for 75 per cent of the Japanese market and 50 per cent of the world market,they are followed by SIEMENS which produces 15,000 to 20,000 control units, PHILIPS, BOSCH and NUM[(42)] which are at par with 4000 per year.[(43)] However suppliers of low cost control units have emerged such as AURKI (Spain), and some machine-tool producers are entering into the production of electronic control units.

3.4.4 Subcontracting and geographical concentration

In industrialized countries machine-tool enterprises buy in some components and rely quite heavily on sub-contractors: the percentage for the value of bought in materiais and subcontracting range from 40 per cent (Europe) to 60 per cent (Japan). The tendency is to increase subcontracting through the greater use of component specialists: items such as ball screws,

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(42) An offshot of TELEMECANIQUE (France).
(43) Machinery and Production, July 1988.

tool holders and base frames are subcontracted.[44]

The Japanese industry is particularly inclined to subcontract and purchase components. This partially accounts for their greater output per employee (Table 6). As in the case of the motor vehicle industry, subcontracting is organized in two layers.[45] (Table 8).

Final builders are generally in charge of assembly, wiring and "adjusting" of the machine tools. They produce the most important pieces such as spindles and in some cases, heavy pieces such as castings. They buy out ball bearings, electric motors, cable and the electronic controls and they subcontract most of machining processes. Each of the 43 machine tool builders is engaged in a subcontracting relationship with 24 subcontractors belonging to a first layer.

The first layer of subcontractors was made up of 1013 enterprises in 1985, and their engineering activities covered all the production needs of the sector: surface treatment, machining, sub-assembly. They are responsible for the production of important components such as the guideway and bearing surface, the manufacturing of which requires not only a high level of technology but also a close technical relationship with the machine tool builders to whom the subcontractors appear to be organizationally linked. Cooperation also exists between subcontractors.

This first layer entertains subcontracting relations with 10,861 small-scale enterprises, half of them engaged in machining activities.

In Japan subcontractors work in close relation with a

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(44) This reliance on subcontracting in one of the factors which can explain the geographical concentration of the industry. It is specially the case in Spain (the machine-tool industry is concentrated in Catalogna and Madrid), and in Italy: 71 per cent of the industry is located in Lombardia and Piemonte. See UCIMU: The Machine-tool industry.

(45) This description can be found in Hiroatsu Nohara: Les acteurs de la dynamique industrielle au Japon LEST/CNRS 1987 and from a communication presented to the symposium High Tech and Society in Japan and the Federal Republic of Germany, Berlin, August 1987.

Table 8: Organization of subcontracting within the Japanese machine-tool industry

MACHINE TOOL ENTERPRISES <------ (43 enterprises)	BUY <------------	ball bearing electric motor bolts wires numerical control

First Layer (1013 enterprises)

Thermal treatment Foundry 216 enterprises (1915 subcontractors)	Press Tinsmith 62 enterprises (1915 subcontractors)	Machining Sub assembly 546 enterprises (5864 subcontractors)
Surface Treatment 41 enterprises (225 subcontractors)	Engrenage 67 enterprises (1212 subcontractors)	others 62 enterprises (615 subcontractors)

Second layer (10861 enterprises)

tinsmith 749 enterprises	thermal treatment 619 enterprises	foundry 858 enterprises
press 345 enterprises	machining 5314 enterprises	surface treatment 667 enterprises
gears 448 enterprises	assembly 358 enterprises	others 1610 enterprises

Source: Technology and division of work within small scale enterprises by The Association of Small and Medium Enterprises Tokyo 1985 relatively smaller number of final builders than in other countries. One of the consequences of this is that technical innovation initiated in the largest firms spread quickly to the small and medium-sized firms. The technological competence of these small firms which used to be a factor holding back the technological advance of Japanese industry has increased sufficiently for such firms to cope with the advent of numerical machine tools. The final builders have been forced to subcontract a larger number of components, and sometimes even the total manufacture of conventional machine tools which are marketed under the final builder's name.

3.5 Production characteristics

3.5.1 Organization of production

The bulk of machine-tool production is for a relatively small batch of products. The process of production includes metal cutting and assembly and to these basic processes can be added inspection, quality control, production planning and design work.

All the problems that affect jobbing machine shops are intensified in machine tool production, the reason being the inherent complexity of the production process in terms of machining and organization. The numbers of components to be produced run into thousands. The task of determining the batch size in which these components are to be produced and the set of machines on which to produce them is extremely complex. Once this has been decided the organizational task of controlling production, ensuring a smooth flow of materials through the plant and preventing work in progress from becoming too large is also extremely difficult.

In a conventional machine-tool factory, the manufactured content is relatively large with many parts made in-house, sometimes including castings. The machining has undergone major changes with the introduction of machining centres which combine milling, drilling and boring. In the case of a CNC machine tool factory, the manufactured content is lower and a large number of components and parts may be sub-contracted, with only finish machining made in-house.

3.5.2. Technology intensive

The machine-tool industry is not a high technology industry;

the ratio of research and development expenditure represents a relatively small proportion of its turnover (on average 4-5 per cent) when compared to other industries such as electronics or pharmaceuticals where R&D represents 5 to 10 per cent of the turnover. Machine tool firms have design offices whose main task is to solve their customer specific problems as they arise from day to day. Links with universities have been traditionally limited, with the exception of Germany (former F R G) where an intricate web of communications among industry, trade associations, unions, and the Government helps to diffuse ideas and to build a consensus in such areas as collaborative research priorities.(46) Links between machine tool firms and universities are established via machine tool technical centres.(47)

The machine-tool industry employs highly skilled professionals in design and production. Ever since the nineteenth century labor intensive machine shops have been a bastion of skilled labour and the locus of considerable shop-floor struggle. The chief means of control of machinists has been their control over the machines. Machining is not a handicraft skill but a machine based skill and traditionally, an important part of the knowledge has consisted of tacit knowledge about the performances of previous generations of machines, their typical conditions of use, and the productive requirements of the users.

With the advent of CNC machine tools and their use in the manufacture of the main components of machine tools, many of the traditional skill-dependent operations have been eliminated even for inspection and testing. The machine tool operator, for example, tends to be someone with mathematical, and programming skills, while changing tools, material loading and unloading are tasks undertaken by semi-skilled operators.(48)

The machine-tool industry tends to become a more capital intensive industry. since only the most sophisticated production facilities and the optimized use of data processing capabilities can ensure an enhancement of productivity.

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(46) About 20 of the university institutes and many of the Fraunhaufer Institutes conduct work pertaining to machine tools. The institute at Aachen is widely considered to be the best machine-tool laboratory in the world while others in Berlin, Stuggart and Hannover are highly regarded.

(47) As it is the case for CETIM in France.

(48) This part will be developed in Chapter 3, 1.2.3.

3.6 The determinants of national advantage in the machine-tool industry

To sum up this introduction to the machine-tool industry, it is useful to assess the reasons why a nation achieves international success in this industry. Competitive advantage in a technology intensive industry does not result from a single determinant; advantage in several determinants combine to create self reinforcing conditions. M. Porter[49] distinguishes four broad determinants that shape the environment in which local firms compete; they can be illustrated by a diamond-shaped figure, as adapted for the machine tool industry (Figure 4). The four determinants of national competitive advantage are:

i) Factor conditions: In the case of machine tool industry, highly qualified skilled labour (in mechanics, and increasingly electronics) appears to be one the most important factors. In industrialized countries, technological centres and industry associations have been important knowledge resources. With the shift to Numerical Control, telecommunications infrastructure will play a larger role than in the past.

ii) Demand conditions: There are several characteristics which make demand conditions among the most important determinants within the diamond in the case of the machine tools:

- The market is highly differentiated; small countries can be competitive in segments which represent an important share of local demand but a small share of demand elsewhere. Another important factor is the rate of growth of the local demand, the faster it is, the faster firms will adopt new technologies.
- Domestic demand should not be considered in terms of volume of sales alone: a large domestic market may give the local manufacturer the opportunity to make use of economies of scale. However the qualitative aspects of the home demand appear to be far more important for the industry than this quantitative aspect: the machine tool

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(49) M. Porter: The competitive advantage of nations. New York, Free Press 1990.

industry's competitiveness is by and large explained by its ability to answer to the sophisticated demand from the local engineering industries, notably the automotive industry and its capability to satisfy its own demand in equipment. The nature of the home buyers appears to be one of the key determinants for success of the machine tool industry which will have less difficulty to adapt to the demand of foreign markets.

iii) Related and supporting industries: Forging, casting, gearmaking, surface treatment facilities are the supporting industries which are needed by the machine tool industry and a close relationship between suppliers and machine tools firms will enhance the technological development of the industry.

The experience from developing countries shows that the setting up of large firms, where supporting industries activities are integrated, has led to many difficulties in terms of capacity utilization. A better approach would be to promote small and medium enterprises so that they could support the machine-tool industry.

iv) Firm strategy, structure and rivalry: As mentioned above, the machine-tool industry is often made up of medium scale enterprises and geographical concentration is often the rule and domestic rivalry is important. While the largest firms will focus on machines which allow long runs of production the smallest concentrate on niche products. In developing countries the creation of monopolies together with the setting up of imports tariffs and non tariff barriers, has often adversely affected the competitiveness of the industry and its capability to satisfy the needs of the engineering industries.

Government role does not appear as a determinant of national competitiveness, however government's industrial policy can influence each one of the determinants within the diamond:

- By providing training facilities it helps promote the factor conditions
- By shaping the local demand through its procurement policy, and by establishing standards and regulations. It plays also an important role in signaling new technology and advertising new markets
- By promoting the supporting industry
- By influencing the firm strategy through its tax policy and trade policy.

CHAPTER II: WORLD MACHINE-TOOL PRODUCTION AND TRADE

1 Production

1.1 World production

During the last two decades, world machine tool production(1) measured in current United States dollars increased from US$8 billion in 1968 to US$19 billion in 1978 and US$42 billion in 1989. This growth was not uniform (Figure 5); peaks were recorded in 1975 and in 1980; the sharp decline from 1981 to 1984 was followed by a steep rise since 1986. These ups and downs were more pronounced when demand was fluctuating in a synchronous way in the different countries as was the case in the 1970s; during that decade industrialized countries' business cycles were closely aligned, while during the 1980s there was a lack of synchronization which has been reflected in the huge internal imbalances.(2) The implication for the machine-tool industry was that international trade could act as a buffer for national production.

The vagaries of the dollar and the floating of world currencies, make it difficult to measure world production in real terms and no attempt has been made to compute a world index.(3) A rough indicator has been worked out using the aggregated production in constant 1981 prices for the four

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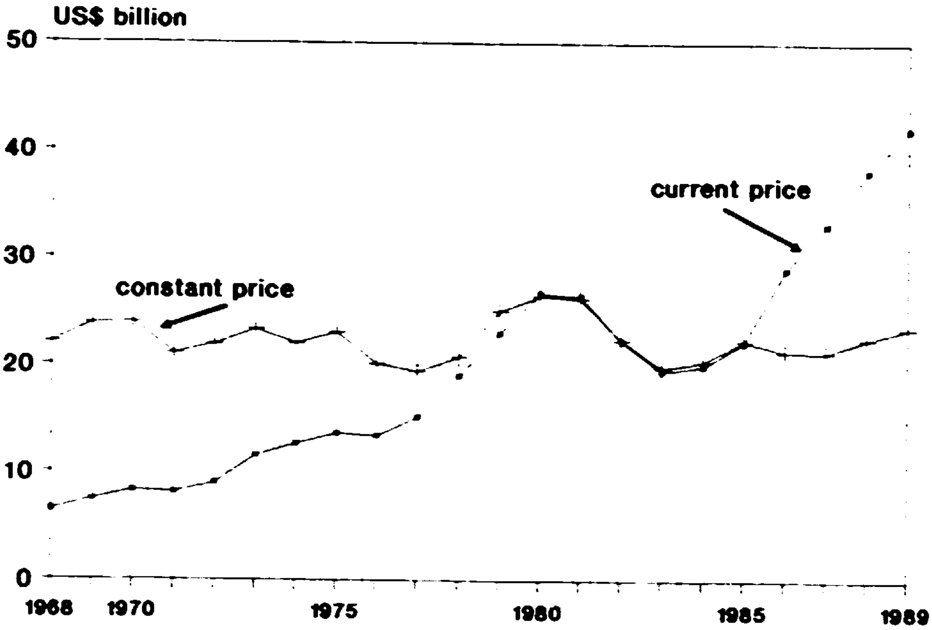
(17) M. L Dertouzos, R.K. Lester, R.M Solow: Made in America, regaining the productive edge, MIT Press, 1989, page 105.

(1) World machine tool production is traditionally measured as the aggregated production of the thirty five-countries reported by the American Machinist review. This total is claimed to represent 95 per cent of world production. Production and exchange data refer to complete machine tools and exclude parts and attachments for most countries.

(2) Economic Focus: "Toppling the business cycle", The Economist, 9 June 1990.

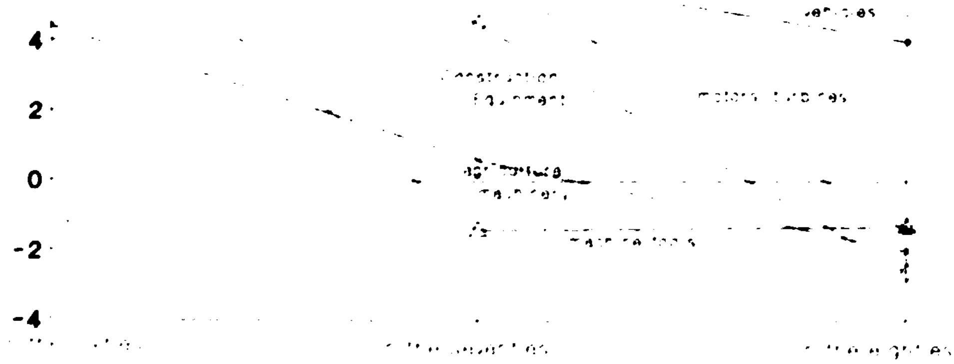
(3) Based on its industrial data base covering OECD countries, the Centre Economique et de Prospective Industrielle et Internationalle (CEPII) has worked out a volume production index. According to this measure, world machine tool demand increased by 8.3 per cent annual growth in the sixties, then fell to a negative growth in the seventies and eighties (-1 per cent).

Figure 5: World production of machine tools



Source: American Machinist and estimates

Figure 6: Evolution of world demand for some mechanical engineering products



largest producers in market economies (accounting for 65 per cent of world production excluding centraly planned economies). The evolution of this aggregate during the last twenty years (Figure 5) can be considered as an approximation[4] of the evolution of world production in volume which appears to have slowly declined over the years: it is a reflection of the slow growth of the mechanical engineering industries in the 1970s and the 1980s (Figure 6). The machine-tool industry is no longer supplying an expanded market and furthermore as discussed below, the link between manufacturing investment and machine tool acquisition is no longer as strong as it used to be.

Table 9 Regional production of machine tools (in millions of US dollars)

	1980		1985		1989	
North America	5043	18.7%	2878	13.1%	3659	8.7%
Western Europe	10869	40.3%	7228	32.9%	16276	38.7%
Eastern Europe and USSR	5475	20.3%	4811	21.9%	8201	19.5%
Latin America	378	1.4%	286	1.3%	505	1.2%
Asia	4828	17.9%	6327	28.8%	12743	30.3%
Others	378	1.4%	439	2.0%	673	1.6%
World	26970	100.0%	21970	100.0%	42057	100.0%

Source: American Machinist

1.2 Concentration of production in industrialized countries

In the late seventies the machine-tool industry was sometimes considered as a mature industry which would eventually "slide out" to intermediary countries.[5] It has not been the case. On a regional basis (Table 9), Western Europe has remained the largest producer (38.7 per cent in 1989) while the share of Eastern Europe and the USSR has been constant. The most noticeable evolution has been the decline of North America's

(4) Considering also the fact that deflators are a very doubtful practice in the case of electronic-based goods.

(5) According to a study by the European Economic Commission (mentioned in UCIMU).

share of production from 18.7 in 1980 per cent to 8.7 per cent in 1989 and the growth for Asia's share from 17.9 per cent in 1980 to 30.3 per cent in 1989, a shift which can be attributed to the growth of Japan's production and that of the East Asian developing countries. Latin American countries' share of production has slightly regressed.

1.2.1 Leading producer countries

Machine-tool production is heavily concentrated in a few industrialized countries. Japan, Germany (former F R G), the Union of Soviet Socialist Republics, Italy and the United States of America accounted for two-thirds of world production in 1988.

This ratio is somewhat lower than the one measured in related[6] industries such as electronics and motor vehicles (Table 10):

- In the electronics industry, the two largest producer countries, the United States of America and Japan, accounted for 63 per cent of world production in 1988, while 79 per cent of world production was concentrated in the five largest producer countries;
- In the motor vehicle industry, 59 per cent of world production is concentrated in Japan and the United States of America and 76 per cent in the five leading producer countries.

(6) Related either in terms of producer-user, as in the case of the motor vehicle industry which is usually the largest market for machine tool, or in technological terms (electronic control).

Table 10 Concentration of production in 1988

	machine tool	motor vehicles		electronics industry	
Japan	23%	Japan	26%	USA	34%
Germany (FRG)	18%	USA	23%	Japan	29%
USSR	12%	FRG	13%	Germany (FRG)	7%
Italy	7%	France	9%	France	5%
USA	6%	Italy	5%	United Kingdom	4%
First Five Largest	66%	First Five Largest	76%	First Five Largest	79%

Sources:
American Machinist; DRI world automotive forecast; Elsevier Macintosh statistics

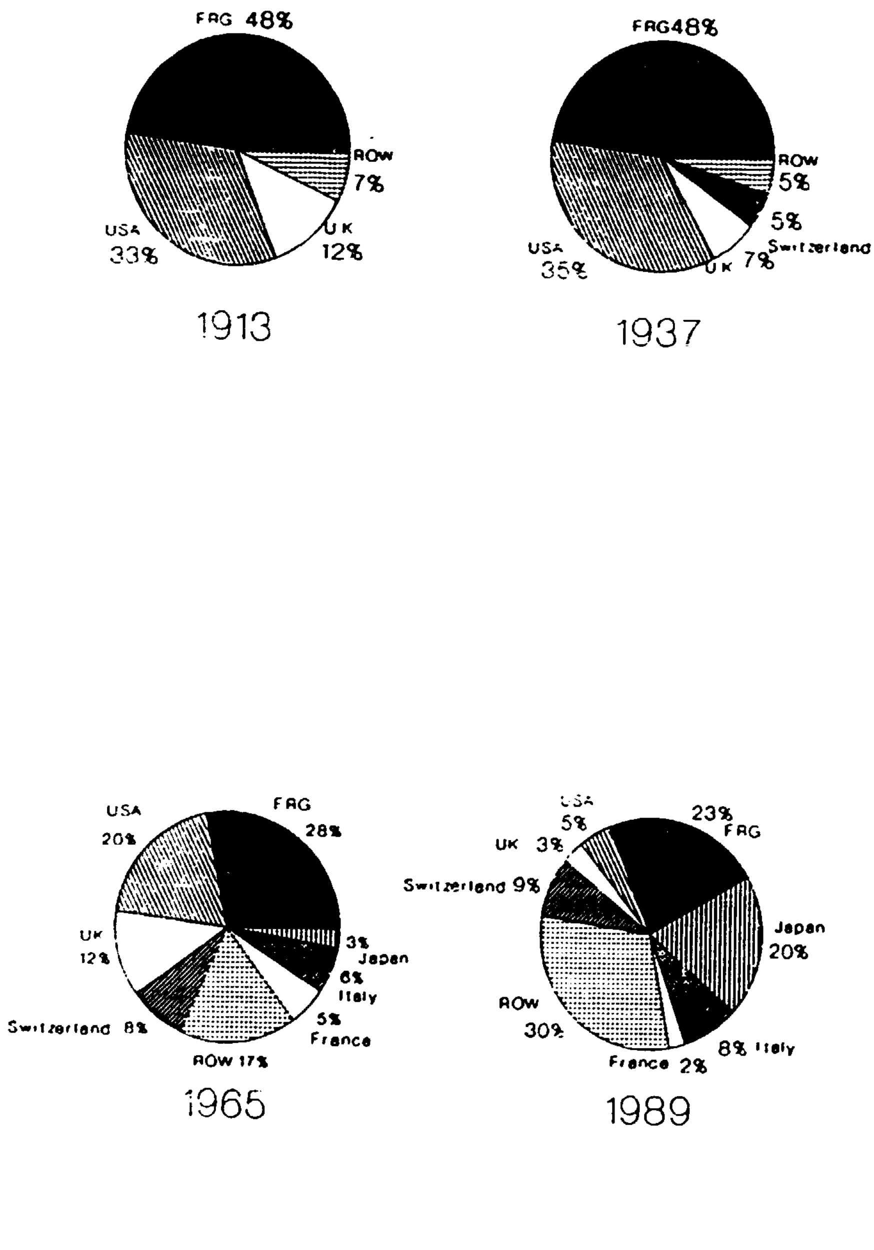
Considered in a long term historical perspective, the concentration of machine tool production has not increased, and on the contrary (Figure 7) there has been a growing number of countries which have successfully entered the industry. In the early part of the 20th century, three countries (Germany, the United States of America and the United Kingdom) accounted for more than 80 per cent of world exports of machine tools; they were joined by Switzerland in the 1930's. After the war, British and American machine-tool industries attained a global supremacy and up to 1960 it was difficult to find a large machine shop where nameplates of the British and American makers could not be found. By 1989, the three leading exporting countries were Germany (former F R G), Japan, and Switzerland.

1.2.2 <u>Shifts among leading countries</u>

Table 11 presents machine-tool production in the 35 main producing countries from 1977 to 1989. Japan has become the largest producer country, replacing Germany (former F R G) in 1982 while the Union of Soviet Socialist Republics remains the third largest producer; it is followed by the United States of America and Italy.

Changes in trade competitiveness were by and large related to the technological breakthroughs achieved in each of the different countries. National Institutions that create resources

Figure 7 Concentration in machine-tool world exports



ROW Rest of the world

Table 11: Machine-tool production (1977-1989) US$ millions

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	in percent 1989
Japan	1602	2350	2982	3826	4798	3796	3541	4473	5316	6872	6419	8722	9817	23.3%
Germany (FRG)	2635	3396	4007	4707	3953	3505	3193	2803	3168	5185	6403	6572	6859	16.3%
USSR	2202	2652	2902	3065	2932	2952	3077	2776	3035	3672	3976	4263	5000	11.9%
United States	2441	3004	4059	4812	5111	3748	2106	2423	2717	2748	2235	2519	3270	7.8%
Italy	878	1060	1354	1728	1513	1138	1037	996	1115	1623	2585	2639	3067	7.3%
Switzerland	580	768	930	994	846	816	766	759	955	1424	1652	1865	1797	4.3%
United Kingdom	588	821	1001	1395	933	781	573	675	783	916	1058	1501	1597	3.8%
GDR (former)	641	699	806	891	828	821	829	789	730	1001	1312	1457	1445	3.4%
France	591	723	877	954	809	621	561	465	499	657	766	876	1081	2.6%
Taiwan (China)	58	126	198	245	294	186	205	244	278	367	578	782	1016	2.4%
PRC	355	405	420	420	440	470	475	482	341	364	632	750	832	2.0%
Spain	191	232	316	353	319	259	193	211	253	396	575	702	795	1.9%
Republic of Korea	57	95	163	130	178	158	119	143	175	333	531	632	760	1.8%
Rumania	120	294	459	590	625	615	439	353	324	306	618	663	708	1.7%
Yugoslavia	141	173	189	232	277	284	231	226	239	390	515	550	602	1.4%
Brazil	283	255	387	315	305	172	98	105	265	370	575	536	458	1.1%
Czechoslovakia	309	363	358	331	358	308	375	325	338	382	405	450	450	1.1%
Sweden	146	166	221	232	205	180	157	158	215	214	258	359	403	1.0%
Canada	71	85	159	194	269	264	290	199	199	209	244	344	383	.9%
Poland	583	679	420	405	310	151	105	121	148	154	323	320	320	.8%
Austria	96	112	101	166	108	160	128	121	120	156	155	247	302	.7%
India	89	112	127	165	209	187	217	264	245	270	278	290	262	.6%
Belgium	106	114	129	137	103	101	85	77	89	150	179	207	194	.5%
Bulgaria	30	30	41	43	201	221	182	192	132	143	140	195	175	.4%
Hungary	105	109	112	121	128	128	135	148	175	180	210	134	124	.3%
Denmark	43	45	50	52	42	50	46	48	58	72	77	78	73	.2%
Netherlands	69	66	83	65	60	48	120	120	43	65	47	78	72	.2%
Singapore	6	12	26	37	43	40	15	21	34	34	35	42	48	.1%
Finland							15	24	20	51	35	42	41	.1%
Argentina	60	60	62	50	35	35	28	23	0		35	48	38	.1%
Mexico	6	14	15	22	24	19	13	25	18	17	21	21	21	.0%
Portugal	10	10	14	16	16	16	13	15	11	13	19	19	17	.0%
Australia	18	19	18	18	69	44	66	66	36	40	45	12	16	.0%
Hong Kong		0	0	0	12	8	5	4	1	1	1	12	12	.0%
WORLD TOTAL	15110	19049	22986	26711	26460	22367	19526	19976	22199	28917	33079	38073	42064	100.0%

Source: Compiled from American Machinist (different issues) and direct them towards specific problems and solutions have represented "systems of innovations": *"When Britain opened up a major technological gap in the first industrial revolution, this was related not simply to an increase in invention and scientific activities.. but to novel ways of organizing production, investment and marketing and novel ways of combining inventions with entrepreneurship. When Germany and the United States overtook Britain in the nineteen and twentieth centuries, their success was also related to major institutional changes (..) similarly when Japan is opening a new technological gap this is related not simply to the scale of R&D but to other social and institutional changes"*.(7)

Indeed, the recent shifts among leading producer countries (Figure 8) are by and large explained by their different attitudes regarding NC technology. This innovation born in the United States in the 1950's was not widely adopted by the American engineering industries, while Japan was a forerunner in the application of NC. Starting in the mid 1970s, the rapid diffusion of NC explained the success of Japanese machine-tool industry in the 1980s. Figure 9 illustrates the dominant position of the United States of America in NC machine tools production in the late 1960s and the shift which has occurred during the 1970s to the benefit of Japan.

From 1978 to 1982, the United States of America was the largest producer country. As a result(8) of the oil crisis the Government put forward an energy saving programme, under which, among other things, it was planned to manufacture more energy efficient vehicles; this created a surge in orders from the motor industry which is the largest client of the machine-tool industry. Since 1981 the share of the United States of America in world production has declined compared to other industrialized countries while that of Japan has grown to become the largest producer country.

It is hard to exaggerate the decline of the US machine tools

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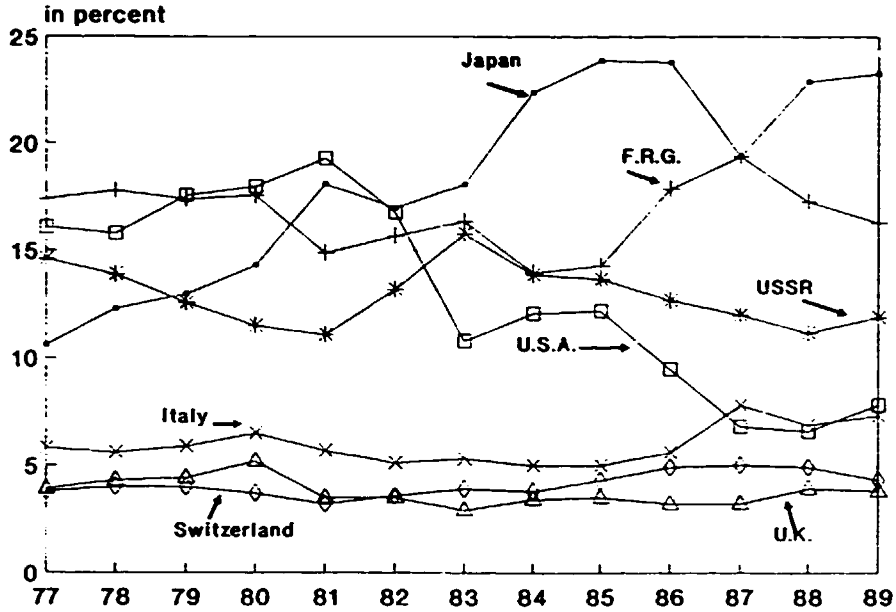
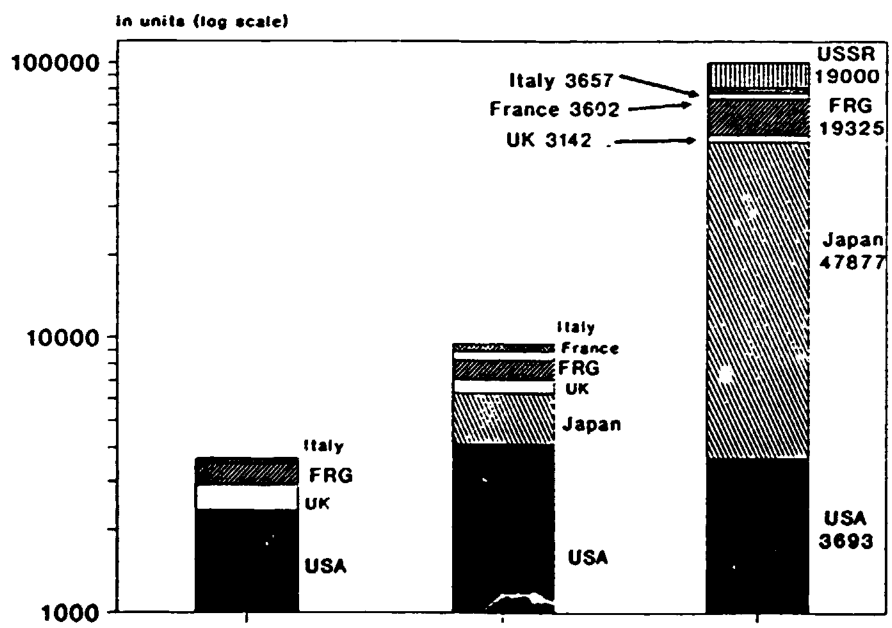
(7) C. Freeman: Technology policy and economic performance: lessons from Japan, London, Pinter 1987 page 31.
(8) B. Real: The Machine-Tool Industry in Technical Change and Economic Policy OECD, Paris, 1980, page 13.

Figure 8: Leading producer countries Share of world production (1977-1989)



Source : American Machinist

Figure 9 : NC machine-tool production



Source : CECIMO, and national statistics industry[9] In the once great machine-tool centre of Springfield, Massachusetts, the largest companies are mostly defunct, having been turned into agents for imported machine tools and occasionally making extra specialized tools for military contractors where costs and quick delivery are secondary.

The American leadership has been taken over by European countries and Japan and this collapse has provoked widespread concern not only about the industry itself but also about its consequences on American manufacturing competitiveness. The MIT Commission set up to identify the main causes of weaknesses in industrial performances, found[10] a pattern of interrelated factors,[11] among which, two are specific to the machine tool industry:

(i) Lack of export orientation, because of their geographic clustering around user markets, the small firms had a regional view of the business, were reluctant to export and were not alert to developments in other countries.
(ii) Failure to capitalize on NC innovation.

The idea of numerically controlled machines was probably triggered off by the electronic gun fire-control developed in the United States for air defense during World War II.[12] This led to the development of the first computer controlled machine

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(9) M.K. Starr (edited by): <u>Global competitiveness, getting the US back on track</u>, The American Assembly, Columbia University, W.W. Norton & Co, 1988.
(10) M. Dertouzos, R.K. Lester, R.M. Solow and the MIT Commission on Industrial Productivity: <u>Made in America. Regaining the productive edge</u>, 1989 The MIT Press Cambridge, Massachusetts.
(11) Among the more general factors: (i) a sharply declining interest in the manufacturing process as a strategic advantage witnin industry and as intellectual keystone within universities (ii) short term investment strategies fostered by Wall Street: under pressure for short term results industrial managers opted for proven technologies rather than take risks with new technologies (iii) absence of commercially oriented government policies.
(12) Nasbetti and Ray: <u>The diffusion of new industrial process: an international study</u>, Cambridge University Press, London, 1974.

tool [13] which began as a government-sponsored project carried out at the Massachusetts Institute of Technology (MIT) Servo-mechanism Laboratory in 1949[14] for the purpose of producing helicopter rotor blades. The military with its emphasis upon performance and command rather than cost, was paramount in determining the development of numerical control. MIT designed a system that was far too expensive and complex for large commercial applications in the engineering industries. The U.S. Air Force transferred this technology to U.S. industries primarily by placing orders for such tools with selected manufacturers and making licences for manufacture available to them. The action made the technology available to several large defense contractors but dissemination throughout the industry was not emphasized[15] and was slow because of the financial limitations of the firms and their innate conservatism. The technology was also disseminated abroad and several Japanese companies were offered licences. Thus during the 1960's the diffusion of NC machine tools was slow and the United States of America lost progressively its leading position.

Several reasons have been put forward to explain this evolution:

a) Attitudes of producers:

(i) The main numerical control suppliers which had dominated the industry with hard wired controls refused to accept the solid state technology until forced to change by competition in the late 1970s[16]

(ii) There was a proliferation of vendors producing numerical controls while no interface standards were being developed and as a result incompatibility of controls

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[13] Development work on NC machine tools began in the United Kingdom in 1950 followed by France and Federal Republic of Germany around 1955.

[14] For more details see Chapter 2.

[15] Clive V. Prestowitz, Jr.: Trading Places, how we allowed Japan to take the lead, Basic Books, New York, 1988, pages 217-237.

[16] OECD: Technology and International competitiveness: an interpretation of the relationship in the machine-tool industry, Directorate for Science, Technology and Industry DSTI/SPR/84.2 Paris, 1984.

became a major problem[17]

(iii) Large machine-tool companies focussed more on the needs of their larger customers and did not appreciate the changing needs of small and medium engineering enterprises for lower cost and more flexible equipment. This bias particularly penalized the US manufacturing industry as a whole.[18] The same adversarial type of relationship between numerical control suppliers and machine tool companies seems to have somewhat characterized the situation in Europe and would explain the slow diffusion of solid state numerical controllers in these countries as compared to Japan.[19]

b) Market characteristics:

(iv) Demand conditions are now recognized as important factors defining a country's competitive advantage:[20] Demanding buyers can exert pressure on companies to innovate faster. This is specially the case for machine tool and the "user pull" is an important stimulus for innovation. Unfortunately this link has been weak in the United States where domestic automakers (in contrast to their Europeans and Japanese counterparts) had opted for proven technologies until recently.

(v) The relationships between users and producers have been adversarial: major users forcing tough price competition among their machine tool suppliers, a practice that discouraged innovations and investment by companies engaged in parts and equipment production.

Between 1960 and 1970, Japanese machine-tool production grew sevenfold, but only a fraction of the output was sold abroad.

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(17) M. L Dertouzos, R.K. Lester, R.M Solow: Made in America, regaining the productive edge, MIT Press, 1989, page 105.

(18) According to a survey made by Carnergie Mellon University, in 1983, out of 25,000 different items produced by one of the largest machine tool firms in the United States of America, 70 per cent were unique. In contrast, 40 per cent of machines produced by Yamazaki in 1984 were standardized products in IFRI, RAMSES 1990, Systeme Economique, Le monde et son evolution, La documentation Francaise, page 146.

(19) OECD 1984.

(20) M. Porter: The competitive advantage of Nations, Free Press, 1990.

While in 1965 Japanese's share of the world export market was 3.6 per cent, by 1980, Japan was exporting half of its output and held 12 per cent of the world market and in 1989 its share rose to 20 per cent. Japanese production overtook that of the U.S. in the early 1980s and this leading position has been reinforced since 1988 when domestic orders surged with the increase in investments which had been delayed since the reevaluation of the Yen in 1985.

Japan has been a pacesetter in developing and using new machine-tool technologies. Efforts for the development of NC machine tools started in the 1950s with the milling machine(21) which deals with a large variety of tools and workpieces and its movements are controlled in three dimensions. Milling machine characteristics made NC programming very complicated and it was with the lathe that the application of NC spread swiftly in the 1970s and contributed to the preeminence of Japanese industry. As indicated by several authors,(22) several features of the Japanese institutional structure made Japan especially well suited for the kind of flexibility required to use the new production technologies to full advantage. Among these features are the nature of labor management relations, the linkages between small and large firms, manufacturing capabilities and industrial policy:

(i) Work organization. It has been observed that during the phase of mechanization of industry in the 19th century, the conception of equipment borrowed heavily from the organization of work prevailing in the shopfloor, "*man had to be mechanized so that machines could be developed*".(23) Similar observations can be made in order to understand the birth of flexible automation in Japan. Since the late 1950s, in order to cope with the small and fragmented nature of their automotive market, Japanese producers have made

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(21) Susumu Wanatabe Market structure, industrial organization and technological development: the case of the Japanese electronics- based NC machine-tool industry, World Employment Programme Research Working Paper, February 1983.

(22) G. Dosi, Laura D'Andrea Tyson, J. Zysman: Trade, technologies and development: a framework for discussing Japan, in Politics and productivity, the real story of why Japan works-A research project of the Berkeley roundtable on the international economy, 1988, page 33.

(23) Perrin: La production des Technologies, Publisud, 1988.

efforts to adopt a more flexible attitude towards production. Their efforts culminated in shop-floor re-organization: "*In order to reduce hangover time, machines were arranged so that workers could move between them, and they were made lighter and less expensive. Consciously, scale economies were sacrificed for the economies of flexibility: these shop-floor reorganizations left Japanese companies and production lines well arranged to absorb the new computer-based production technologies*".(24) This organization created a most favorable environment for the conception and diffusion of numerically controlled machine tools.

(ii) Company organization. While American firms invented microprocessors, Japanese firms have been the forerunners in their applications. Almost every large Japanese automobile manufacturer has a large machine-tool operation in which 200 to 400 people are exclusively engaged in the development of new tools which are then quickly introduced into the production process. When the machine tool has proved to be appropriate within the factory, it is then sold on the market. The Japanese machine-tool market is highly fragmented, shared among many producers who develop equipment for their own internal purposes and then sell it on the open market.(25) Some of the machine-tool firms had the additional advantage of having acquired experience in the production of microprocessors:(26) FANUC began as a division of Japan's largest computer maker, FUJITSU, from which it was separated in 1972. Although its speciality was the production of computer control equipment, Fujitsu also produced machine tools. The firm's unique orientation served it well in the race to develop more flexible machine tools. "*We applied the technological innovation in semi*

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(24) S. Cohen, J. Zysman: Manufacturing matters, the myth of post industrial economies, Basic Books, 1987, p.146.

(25) C. Johnson, L. D'Andrea Tyson, J. Zysman: Politics and productivity, the real story of why Japan works, a research project of the Berkeley Roundtable on the International economy (BRIE), Ballinger, 1989.

(26) Robert H. Ballance: International industry and business, structural change, industrial policy and industry strategies Allen & Unwin, London 1987, page 297.

conductor earlier than the computer industry."[27] In contrast to what happened in the United States of America, the design and manufacturing of the control part was concentrated within FANUC with the active encouragement of the Ministry of Trade and Industry. This not only led to economies of scale but also avoided the incompatibilities that plagued American machine-tool users. Machine-tool builders were relieved of the burden of developing their own controls, and FANUC's concentration on the electronic side of electromechanical products reduced direct competition between itself and the builders. FANUC gained 80 to 90 per cent of the Japanese market for controls during the 1970s and 40 to 50 per cent of the world market by the early 1980s.[28]

(iii) Manufacturing capabilities. Flexible automation equipment is a typical product of "mechatronics", that is to say a combination of mechanical engineering and electronics. The development of the mechatronics indus ry in Japan owes much to the technological level of the precision machinery industry, and the increasing reliability of electronics devices.[29]

- The mass production of consumer durables such as watches, sewing machines, cars, etc. had established the mechanical engineering base for the precision machinery industry in Japan: miniature bearings used in video tape recorders are good examples of this high level of engineering required to machine with sub-micron accuracy.
- It was not until large scale integrated circuits began to be utilized in the mid-seventies that electronics had the reliability needed for mechatronics; in addition technological developments in sensors, actuators (in servo motors converting electronic signals into the movement of mechanical devices) were also indispensable.

(iv) Economic constraints. One of the main reasons for the strength of the Japanese NCMT industry on the international

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(27) According to the President of Fanuc as recorded by Jacobsonn in Flexible Automation (1988).
(28) In Made in America, page 106.
(29) Takemochi Ishii: Mechatronics and Japanese Society in Mechatronics, development in Japan and Europe. Edited by Mick McLean, Frances Pinter (publishers), London, 1983.

market is the fact that NC systems were being domestically manufactured when productivity improvement began as an urgent task for industry. The acceleration of the diffusion of numerical control machine tools owes much to the response of Japanese firms to new constraints which arose in the 1970s: These were the impact of the economic crisis in 1974/1975 (machine tool production fell by 25 per cent) and the appreciation of the yen in 1977. To cope with these constraints, small and medium engineering industries adopted techniques that reduced the time and money involved in shifting products and increased the sophistication and quality of their product. This resulted in a rush of orders for NC machines tools which are very effective in reducing labour and promoting rationalization.[30] The situation in other industrialized countries was the same as in Japan, but, according to the Executive Director of the Japan Machine Tool Business Association,[31] machine-tool makers made little effort towards the development of NC tools in those other countries, and this increased the demand for Japanese machine tools.

v) Industrial policy. A key feature of Japan's industrial strategy has been the targeting of industries on the basis of their perceived potential for economic growth. The first law for the promotion of Specified machinery industries was written by MITI and passed by the Diet in 1956; in 1957 the first basic plan for the industry adopted the objectives of reducing costs, improving quality and raising productivity through centralization of manufacturing. The goal was for certain producers to concentrate on only a few products thereby increasing the scale of production. MITI was convinced that custom production of small lots by small manufacturers would always result in a system that was undercapitalized and vulnerable to cyclical swings. The Japanese machine tool builders were encouraged by MITI to develop modular standard products suitable for a wide range of users. Simple modular designs that minimized parts counts

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(30) The adjustment by small and medium enterprises can be illustrated by the evolution in the share of these enterprises in total demand for machine tools which increase from less than 40 per cent before 1975 to 60 per cent between 1977 and 1982 in Dafsa: L'industrie mondiale de la machine outil, Paris 1983.

(31) Abe in Business Japan, cited in Piore and Sabel: "The second industrial divide".

also kept costs down and cut lead time. Builders concentrated on the needs of small users and tapped high volume markets: they specialized in a particular type of machine and this specialization helped to achieve economies of scale. The development of the industry caught the established competitors off guard.

These plans were supported by a panoply of market protection measures coupled with various financial incentives. Until 1983, MITI used special tax incentives to encourage Japanese manufacturers to purchase and install robots and numerically controlled machine tools and companies were sometimes given hidden subsidies.(32) Although the primary objectives were to raise productivity levels and reduce hazardous working conditions, the switch to automated equipment had the effect of boosting the demand for high-tech products. Companies buying robots and NC machine tools received a 13 per cent tax credit on the purchase price, on top of regularly scheduled depreciations allowances.(33)

1.2.3 <u>Europe maintains its position</u>

Within Europe, Germany (former F R G) has taken the lead. German firms have stressed high precision and special capabilities. The market niches dominated by German builders tend to be in high end equipment and each firm produces a limited range of sophisticated machine tools. The user pull stimulus for

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(32) As for example lucrative sugar import licenses and latter hidden subsidies derived from State revenues coming from gambling on bicycles and motorbike races. Capitalizing on the fact that bycicle racing is a popular sport in Japan, MITI passed a law allowing municipalities to organize races and betting on them. A portion of the money went to the Japan Bycicle Rehabilitation Association controlled by MITI. The organization budget has totalled over US$2 billion and has proven a substantial source of off-budget funds for various MITI projects including the machine-tool industry which could have received US$1 billion. See Clide V. Prestowitz, Jr.: <u>Trading places, how we allowed Japan to take the lead</u>, Basic Books Inc, 1988, page 222-223.

(33) In D.I. Okimoto: <u>Between MITI and the market, Japanese industrial policy for high technology</u>, Standford University Press, 1989, page 101.

innovation is important and major customers are deeply involved in development efforts for new machines and show much collaboration and trust; their tendency to put technical performance at the top of their purchase criteria has helped to drive innovation.

While Germany (former F R G) is the established leader of the European machine-tool production, and the second largest producer in the world, the growth of Italian machine tools industry has also been dynamic. Although the Marshall Plan for Europe and the Italian Government helped finance the start up of machine-tool builders in the post-war years, it was in the 1970s that Italian production really began to expand beyond its national borders. Italy has ranked fifth producer of machine tools since 1978 and in 1988 the output of the Italian machine tool industry exceeded that of the United States and reached an estimated 7.5 per cent of the world total. As in the case of Japan, the growing demand for flexible equipment from small and medium-sized firms led to a boom in production of NC equipment and Italy is the second largest producer of such equipment in Europe.

Europe remains the leading source of technology as can be seen in Table 12 which shows the number of applications by EC countries, EFTA, Japan and the United States of America for a patent in more than one country between 1982 and 1988 covering key technologies related to the machine tool industry. With respect to control and robotic technology the table shows that the number of European patents have been slightly higher than those for Japan.

Box 6: The Reunification of German machine-tool industry

One result of the reunification of Germany is the end of Comecon-second largest machine tool industry- which was the fifth largest world exporter.

The former East German industry had its roots in the pioneering traditions that made Saxony the cradle of German machine tool industry. The industry was restructured in the late seventies into three combinates: Fritz Eckert which specialized in prismatic parts, 7th October for rotational parts and Unformtechnik Herbert Warnke Erfurt for metalforming machines. These groups monopolized the entire production chain.

GERMANY (FRG)	GERMANY (GDR)
Trade Association	State Trading Company
VDW	WMW
Gross production: in 1989 (US$ mi)	Gross production: in 1989 (US$ mi)
6800	1400
Structure:	Structure:
300 companies	3 Combines
Employement:	Employement:
94000	80000

Adapted from: The autobahn's new Eastern lane American Machinist, May 1990.

Table 12: Number of patents applications 1982-1988

Technology	EEC	EFTA	JAPAN	USA
Mechanical	9253	2169	4371	5082
Controls	3852	552	3093	2746
Robotics	656	152	582	393
Laser Manufacturing	339	57	193	241
Laser sources	672	28	844	684
EDMs	112	92	241	50
Ceramics	1511	159	1631	1237
coatings	1453	179	1504	1537
Powder metallurgy	443	106	459	495

Source: Strategic Study on European Community Machine Industry, Brussels, 1990

1.2.4 The case of the USSR

Although rated as the third largest manufacturer of machine tools by the NMTBA classification (Table 11), the USSR is probably the largest world producer and importer since NMTBA uses only the MINSTANKOPROM figures omitting other ministries[34] which produce machine tools (e.g. for automotive and defence).[35] The machine-tool industry is said to employ 1.8 million workers at more than 9000 research institutes, design bureaus and production enterprises. It is responsible for more than a quarter of the country's industrial output.[36] The 12th Five Year Plan released in 1986 called for a 43 per cent increase in production over the five years and rapid development of CNC machine tools. According to Stankoimport, about 50 per cent of machine tools installed in the USSR are manually controlled and 16 per cent of Soviet built machines have CNC.

(34) There are eight ministries responsible for the machine-tool industry.

(35) Machinery and Production engineering: "The cue for capitalism, an international report", 5 January 1990.

(36) Financial Times: An ill-equipped hub, 12 March 1990.

1.2.5 The second tier

The changes which have occurred among the leading producer countries should not prompt one to overlook the growth in the countries which may be ranked among the "second tier", that is countries with machine-tool annual production value-added of between US$100 millions and US$1 billion. Between 1978 and 1988 (three years average), the share of world production of these seventeen countries has been around 20 per cent.

The largest producers among this group are France, Taiwan, Province of China, People's Republic of China, Spain, Romania, Republic of Korea, Yugoslavia and Brazil. During the last ten years the most dynamic countries (ranked in terms of growth rates) have been: the Republic of Korea, Taiwan, Province of China, Spain and Yugoslavia. In these countries the rapidly growing economies have given a strong impetus to their machine-tool industry which in some cases is also highly export-oriented.

Among the other countries, the more noticeable evolution has been the relative decline of Poland and Czechoslovakia which possess large industrial bases and very old traditions in machine building. Production has stagnated (in relative terms) in India and Sweden. The latter is a small producer of machine tools with only 20 firms, but a pioneer in technology. Sweden was the first European country to build CNC machine tools.

1.3 Machine-tool production in developing countries(37)

1.3.1 Overall assessment

The share of developing countries in world production of machine tools is extremely limited: smaller than 7 per cent in 1978, 9 per cent in 1988, a ratio which can be compared with developing countries' share of world electronics output (around 14 per cent). Four categories of developing countries have been identified:(38) (i) Countries with little or no manufacturing of machine tools; (ii) Countries with the capability to manufacture machine tools but which were yet not committed; (iii)

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(37) This part provides an overview of machine-tool production in developing countries. Deeper analysis can be found in the country case studies carried on by several UNIDO consultants in Bolivia and Peru, Algeria and Tunisia, the Republic of Korea, India, China and Latin America.

(38) ECDC meeting on machine tool in Buenos Aires in 1988.

Countries with the capability to manufacture basic machine tools and wishing to diversify into advanced CNC manufacture; and (iv) Countries which could be considered as established suppliers of different types of machine tools including CNC. Around fifteen developing countries belong to the first group[39] and developing countries' production is heavily concentrated in the ten countries[40] which belong to groups (iii) and (iv).

The existence of a developed engineering industries base is the first prerequisite to enter the machine-tool industry for two reasons. On the demand side, engineering industries are by and large the main market of the machine tool sector (see Figure 17, in 2.2.2.) while on the supply side the existence of supporting industries (i.e. castings, forging, high grade steels, electric motors, high tensile nuts and bolts, tools, jigs and fixtures, electronic control) are needed for the setting up of a machine-tool industry.

The viability of a machine-tool industry in a developing country depends not only on the volume of production of the engineering industries but also on their composition:

-In the low income developing countries, the engineering industries are embryonic and consist mainly of metal products manufacturers (production of metal containers, domestic appliances, furniture etc aggregated in ISIC division 381). The production of these items hardly requires any machining and can usually be achieved with the use of simple metal forming tools. In these countries, metal cutting machine tools are mainly used for maintenance and educational purposes.

-In countries where the engineering industries output is more important, the share of simple metal products manufacture (ISIC 381) represents from 30 to 50 percent of the total engineering industries value-added. The firms engaged in production and maintenance of non-electrical machinery (ISIC 382) and transport equipment (ISIC 384) are the main users of machine tools. The growing needs of these two sectors offer a market for machine

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(39) In several developing countries machine-tool producers are seldom not recorded by industrial statistics, being either too small units or integrated within diversified metal working firms.
(40) That is: Brazil, China (PRC), China (Taiwan), Yugoslavia, Republic of Korea, Argentina, India, Mexico, Singapore and Hong Kong.

tools which can sometimes justify the setting up of a domestic industry.

Table 13 documents the relationship between machine-tool production and the development of engineering industries in developing countries. It presents the value-added as well as the structure of engineering industries of developing countries which report such statistics to UNIDO. It appears that countries which have entered into machine-tool production in a significant way are characterized by a value-added of engineering industries superior to a "benchmark" of US$ 1 billion (in 1987); some production is recorded in countries where the value-added of engineering industries is between US$100 millions and US$1 billion.

In most machine-tool producer countries, the combined share of non-electrical machinery, transport equipment and precision machinery represents more than 40 per cent of the engineering industries value-added.

1.3.2 Latin America

The economic growth of Latin American countries stalled in the 1980s under the debt burden. The performance of the industrial sector weakened (from an average growth of 6.4 per cent between 1971 and 1980 to 1.0 per cent between 1981 to 1988) and displayed great fluctuations. The ratio of gross domestic investment to Gross Domestic Product has decreased from an average of 23 per cent (1970-79) to 18 per cent (1980-86). In constant US$ (1986) Latin American gross investment fell from US$192 billions in 1980 to 141 billions in 1987 and in per worker terms gross investment declined from US$1634 (1980) to US$1039 (1987).[41]

These macro-economic evolutions have had a negative impact on the capital goods sector where Latin American countries had achieved substantial gains in the 1970's. The transport equipment and non-electrical machinery subsectors have experienced declines in production of respectively -2.3 per cent and -2.6 per cent per year between 1980 and 1987.[42] This

(41) Inter American Development Bank: Economic and Social Development in Latin America, Washington, 1988.

(42) Computed from UNIDO figures.

Table 13: Engineering industries and machine-tool production (US$ millions)

	Engineering Industries (ISIC Classification)						Machine Tools
	1987	381	382	383	384	385	1989
PRC (China)	22000						832
Brazil	20932	17%	30%	25%	26%	2%	449
China (Taiwan)	10989	16%	14%	51%	15%	3%	695
Yugoslavia	8378	28%	23%	26%	21%	2%	671
Korea (Republic of)	8219	18%	20%	53%	39%	4%	597
Argentina	5897	30%	17%	15%	37%	2%	38
India	5882	9%	30%	29%	29%	3%	272
Mexico	5630	23%	18%	20%	33%	5%	18
Iran	3696	21%	22%	29%	44%	2%	p*
Singapore	3062	11%	14%	56%	16%	3%	37
Hong Kong	2557	20%	12%	46%	6%	16%	1.50
Nigeria	1825	24%	5%	8%	63%	0%	
Venezuela	1735	32%	16%	20%	31%	2%	
Thailand	1681	13%	16%	19%	50%	2%	
Algeria	1561	34%	21%	15%	29%	1%	18
Iraq	1366	30%	26%	42%	2%	0%	p
Egypt	1328	18%	21%	33%	27%	1%	p
Malaysia	1192	12%	10%	57%	19%	2%	p
Philippines	729	20%	9%	61%	9%	2%	
Syrian Arab Rep.	715	45%	19%	30%	5%	0%	
Colombia	705	33%	11%	27%	24%	5%	
Peru	610	32%	21%	26%	19%	3%	1
Indonesia	526	34%	12%	20%	33%	0%	1
Chile	317	45%	18%	20%	16%	1%	
Pakistan	281	12%	22%	38%	27%	2%	5
Zimbabwe	220	43%	18%	28%	11%	0%	p
Ecuador	161	43%	5%	34%	13%	5%	
Tunisia	160	58%	1%	23%	18%	1%	p
Morocco	146	45%	10%	27%	16%	1%	p
Uruguay	143	29%	10%	27%	34%	1%	
Nicaragua	134	81%	3%	8%	5%	2%	
Kenya	115	23%	13%	39%	25%	0%	
Malta	79	19%	8%	48%	9%	16%	
Zambia	65	40%	14%	23%	23%	0%	
Bangladesh	61	20%	36%	18%	20%	7%	p
Dominican Republic	58	72%	10%	16%	0%	2%	
Cyprus	55	53%	27%	13%	7%	0%	
Bolivia	47	57%	23%	13%	4%	2%	
Senegal	46	52%	17%	4%	26%	0%	
Guatemala	39	41%	8%	36%	13%	3%	
Panama	39	59%	3%	18%	13%	8%	
El Salvador	37	30%	24%	41%	0%	5%	
Honduras	37	65%	3%	24%	8%	0%	
Sri Lanka	33	33%	24%	30%	12%	0%	
Cameroon	31	3%	68%	16%	13%	0%	
United Rep. Tanzania	31	42%	6%	10%	42%	0%	p
Jamaica	17	35%	6%	18%	41%	0%	
Ethiopia	11	91%	0%	9%	0%	0%	p

*p: recorded production (no figure)

No figures are available for Cuba and Democratic Republic of Korea crisis has seriously eroded the position of the Latin American industry.

Local production in Argentina started in 1903 and by the end of the 1920s several enterprises had been established by immigrants, often as repair shops which moved into production based on reverse engineering and protected by foreign exchange restrictions. Production began on a large scale in the 1960s and the early 1970s were considered as the "golden years" for industry and by 1973, some 73 firms and employing 13,000 workers had been established. Production reached a maximum of 22500 units in 1973, and 5000 units were exported. However by 1985 the output had fallen to represent one tenth of 1973 volume while employment decreased to 2500.

The industry was strongly affected by the economic crisis and the sudden and drastic reduction of protection. Investment and domestic production dropped and many machine-tool companies went into bankruptcy. Some producers which had been able to compensate for the contraction of the domestic market by exporting to other Latin American countries were affected by the downturn in these economies. After years of deep crisis production rose to US$35 millions in 1987. Import share of apparent consumption which fluctuated around 50 per cent has risen significantly since 1980 and between 1986-1988 the growth of export has somewhat compensated the decline of domestic consumption. (Figure 10)

The industry is composed of four broad groups in terms of sales and technological levels.(43) In the first, there are three enterprises producing NCMT routinely (lathes, milling machines and machining centres) and operate with foreign licenses; the second group is composed of three firms producing metal forming machines; thirty small firms compose the third group while the fourth group is made of subcontracting companies with limited technological capability.

The Brazilian (Figure 11) machine-tool industry is the largest in Latin America. Local production was given a major impetus during the Second World War when imported supplies were cut

(43) D. Chudnowski: The diffusion and production of numerical controlled machine tools with special reference to Argentina, World Development, vol 16 no. 6, 1988.

Figure 10: ARGENTINA
Production, consumption and trade

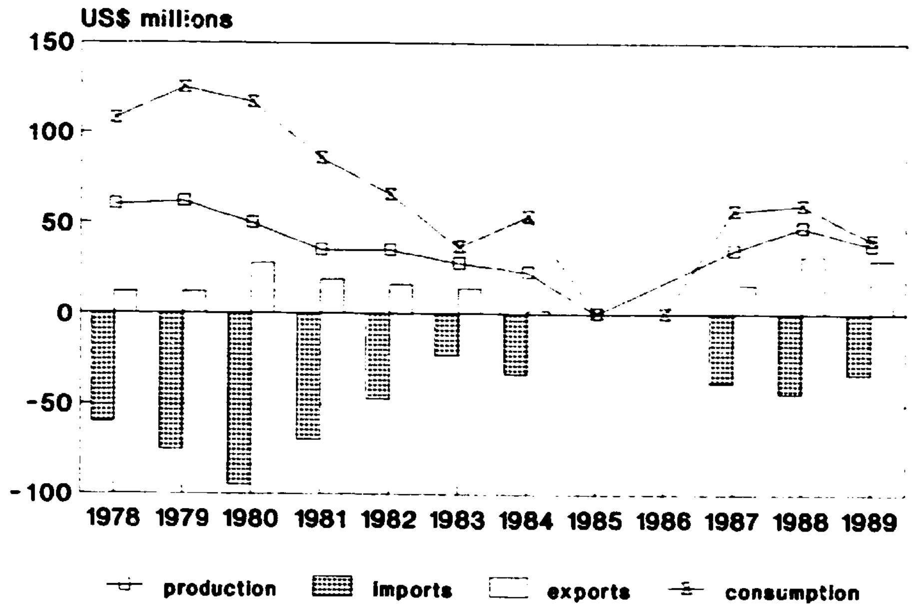
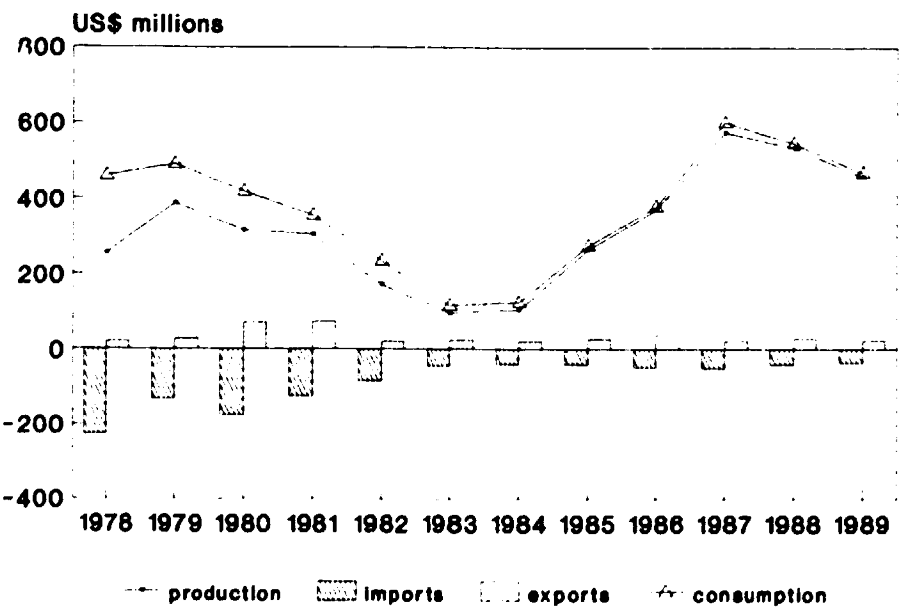


Figure 11: BRAZIL
Production, consumption and trade



off. While there was some decline in domestic manufacturing at the end of the war with the lifting of import restrictions, the growth of the engineering industries was sufficient to maintain interest in local machine tool production. In 1970 Brazil produced half its requirements and exported within the Latin American Free Trade Arrangement.

The industry expanded throughout the 1970s from a production value of US$33 million to US$400 million. The economic crisis which led to a sharp reduction of the domestic market and, subsequently of the main export market (Mexico) led to a drastic reduction of output, and the industry underwent five years of deep recession (1981-1986). Due to the severe shortage of foreign exchange and the centralization of imports payments, machine tool builders were sometimes unable to purchase parts and materials from foreign suppliers. Many companies, which were unable to export to non-Latin American countries, were operating at very low capacity and many went bankrupt. Due to the reflationary effects of the Cruzado plan (1986) the domestic market somewhat recovered and production increased in 1986 and 1987; however production fell again in 1988 and in 1989.

In Brazil and Argentina, the crisis has widened the technological gap. Local production of numerical control machine tools accounted for 36 per cent of machine-tool production in 1986/87 (742 units produced in 1988). The increase in import penetration in Brazil goes parallel with a reduction in apparent consumption.

One[44] can distinguish three broad groups of enterprises. The first is composed of a dozen subsidiaries of foreign firms which were attracted by the development of the automobile industry; they produce transfer lines, NC lathes, NC boring machines, machining centres and a wide range of complex machines. The second group is composed of a dozen large and medium Brazilian firms which concentrate on conventional machine tools and have recently moved into numerical control. A third group is composed of eighty small and medium-sized Brazilian firms which manufacture universal conventional machine tools.

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(44) F. Erber: Co-operation in industrial automation between Argentina and Brazil. UNIDO December 1989.

Domestic production in Mexico first started in the 1930s.[(45)] However many plants failed to survive after the Second World War because of outdated technology and strong import competition. Activity in machine tools started again in the 1960s and, during the oil boom of the seventies, production expanded from US$2 million in 1974 to a peak of US$24 million in 1981.

The industrial policy followed by Mexico did not foster the development of this industry. The capital goods industry was given a low level of protection, and Government agencies as well as the private sector, in general, found it easy to import capital goods. State enterprises enjoyed an unlimited access to imported equipment at zero tariffs rates.[(46)] Mexico is the largest importer of machine tools among Latin American countries, and imports cover more than 80% of domestic consumption. The rise in consumption in recent years (US$255 million in 1988) has not impulsed a parallel rise in domestic production (US$ 18 million in 1988).

Local production is extremely limited and covers less than 10 per cent of domestic demand; the machines manufactured are simple conventional machines while 40 per cent of imports are NC machine tools and machining centers.

The number of machine-tool producing firms has decreased from 30 in 1966 to 7 in 1980 and 4 in 1989 which together have 295 workers. The largest companies are two joint-venture companies. FAMA (Fabrica de Maquinas y Accessorios) with a turnover of US$ 3 million in 1988 which is a joint venture involving STROJIMPORT from Czechoslovakia. OERLIKON MEXICANA is a joint venture with OERLIKON Switzerland; its turnover was US$1 million in 1988. Several companies have disappeared since 1980, such as INDUSTRIAL LAGUMERA, which was the oldest machine-tools manufacturer.

Among the other Latin American countries, machine-tool production takes place in Colombia, Cuba, Peru and Venezuela.

There are three major producers in Colombia. One developed from the repair shop of a major textile group. It originally produced engine lathes, bench, column and radial drills and

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(45) M. Humbert and O. Castel: Machine Tools in Mexico, UNIDO, 1990.
(46) World Bank: The manufacturing sector: situation, prospects and policies, Washington 1979.

planning machines. It started without a license agreement and acquired the technical know-how from a Czechoslovak firm. Two other lathe producers were operating under licence agreements with Spanish firms. A number of firms produced metal forming equipment such as eccentric presses and hydraulic presses.

There are 55 machine-tool establishments with a total employment of 500 in Peru (1987)[47] where production started in the 1970s. Local production was US$ 836 thousands in 1988 and covered 5 per cent of local demand for metal cutting machine tool and 11 per cent for metal forming machine tools. Main products manufactured are parallel lathes, hydraulic presses and milling machines with licensing agreements with Argentina, Brazil, Italy, Czechoslovakia, Bulgaria and Romania.

1.3.3 People's Republic of China, India and Pakistan

In the People's Republic of China (Figure 12) machine-tool production began in the 1930s. The plants which were destroyed during the Second World War were reconstructed and twenty large scale machine-tool plants were built during the 1950s. In the 1960s additional plants were set up while the focus was on the dispersion of the industry.

The sector which includes manufacture of machine tools and accessories as well as wood working machines employs 600,000 people and production value stood at US$832 millions in 1989. It comprises over 400 small, medium and large scale plants among which 121 are considered the main enterprises which operate under the direction of the Ministry of Machine Building Industry.

Chinese production used to cover almost all its needs; however following the modernization programme launched in 1978, imports dramatically increased and accounted for about fifty per cent of apparent consumption in 1988, as opposed to 14 per cent in 1978, while the share of exports in production also rose from 5 per cent in 1978 to 15 per cent in 1988. Developing countries, especially in South East Asia are among the main markets.

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(47) J. Gonzalez-Roda: La Industria de Maquinas-Herramienta y la difusion del control numerico en el Peru y Bolivia, UNIDO February 1990.

Figure 12: CHINA
Production, consumption and trade

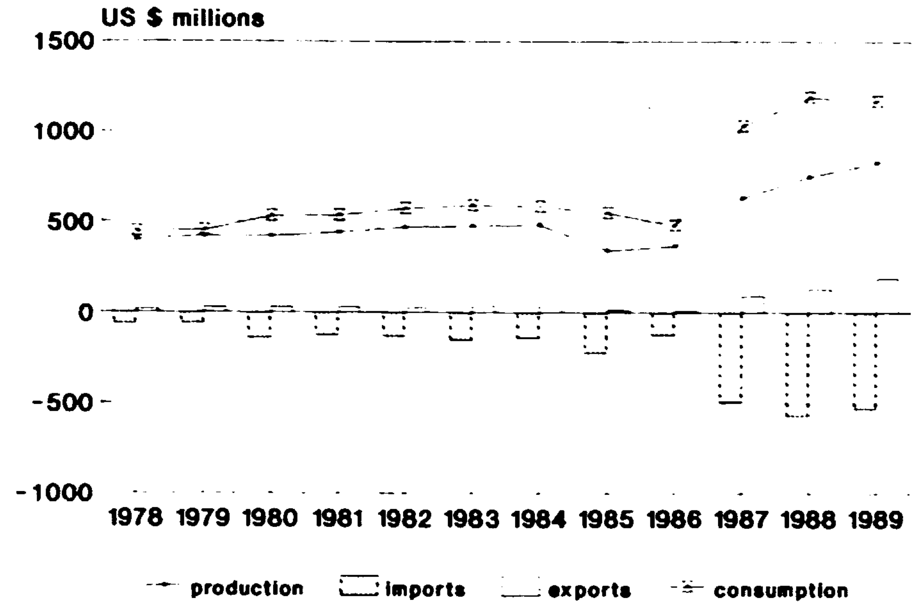
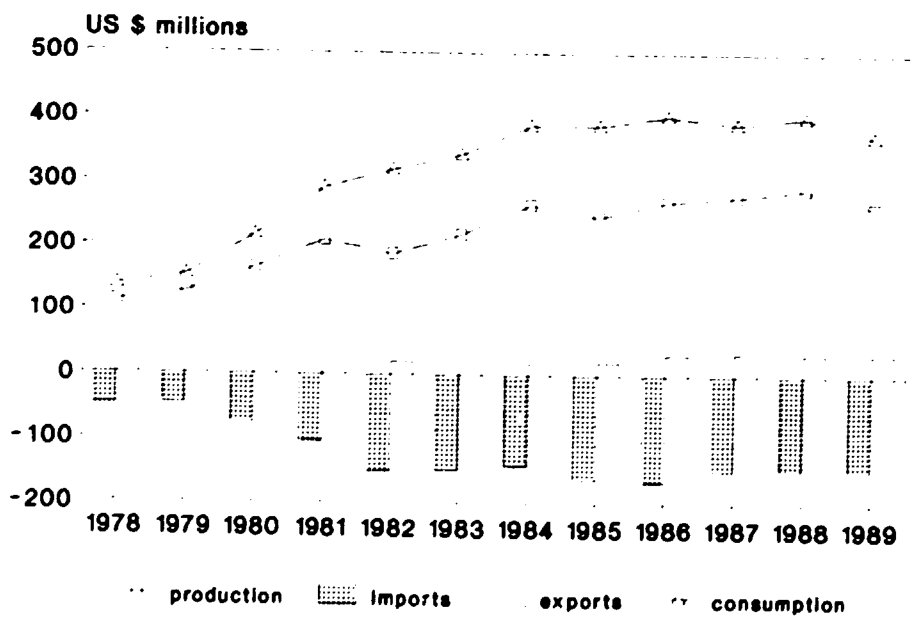


Figure 13: INDIA
Production, consumption and trade



The People's Republic of China produced 151,800 metal cutting machine tools in 1985 and an estimated 161,000 in 1986:[48] these production figures are underestimates since a large number of enterprises produce machines for their own use. In 1982, China's installed machine tools were estimated at about 3 millions units, which when compared to the installed capacity in industrialized countries (2.3 millions in the United States), appear excessive. This is partly explained by the adherence of the Chinese industry to the principle of self-sufficiency and the fact that contrary to the practice in the industrialized countries where old and obsolete machines are replaced with modern machines, in China old machines are kept and new machines are simply added.[49]

Indian machine-tool production (Figure 13) began in the 1930s and the total number of manufacturers before World War II was estimated to be 100. The outbreak of the war forced manufacturers to produce defence equipment which increased the demand for machine tools. The British Government in India passed the Machine Tool Control Order in 1941, the main object of which was to regulate and improve production and secure the best quality machine tools for the war industries. The cut-off of imports called for greater efforts by the local industry: 20,000 machine tools were produced over the 6 year war period compared to 273 in 1941.

After the war the industry was unable to sustain competition from imports and the number of firms decreased from 125 to 45. The new Indian Government decided to help the machine-tool industry. A collaboration agreement was signed with OERLIKON and BUERLHE (Switzerland) to set up HINDUSTAN MACHINE TOOLS Ltd. (Bangalore), which started production in 1955. The industry was given incentives, and imports were either restricted or banned. Numerous other agreements were signed with leading manufacturers in Europe, Japan and the United States of America. The production met a growing demand of domestic consumption, from 23 per cent in 1961 to 71 per cent in 1971 and 70 per cent in 1980.[50]

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(48) American Machinist, February 1987.

(49) IBRD: Staff appraisal report, Shangai machine-tool project, Washington, 1987.

(50) According to American Machinist figures while according to Indian statistics it was 86 per cent in 1979.

By the late 1970s, the Indian machine-tool industry was able to manufacture most of the general purpose machines required by the local users. HMT started developing NC/CNC machine tools in 1970 through its own R&D efforts; however the local user industry did not show much interest in this technology.[51] When the Government introduced liberalized measures in the early 1980s, large scale imports of special purpose machines and of CNC machine tools took place which accounted for the increased share of imports in domestic consumption (40 percent of domestic consumption in 1988). Technological cooperation helped Indian machine-tool firms to introduce CNC machine tools (300 produced in 1986) and if the trend continues, the share of CNC machine tools will constitute 30 per cent of the total production by 1994.[52]

Machine-tool exports have been increasing and the Union of Soviet Socialist Republic has become the the leading market for Indian exports as a result of a new co-production agreement signed between the two countries in 1987. Exports have increased to other industrialized as well as developing countries where HMT has established some turnkey machine-tool projects. Japanese machine tools represent one-quarter of the import market. Imports from Taiwan, Province of China, and the Republic of Korea are on the increase; these two countries serve the small-scale industries where demand has been growing.

In Pakistan[53] the production of firearms which started in 1860 offered the basis for growth of the machine-tool industry. A centre lathe was built in 1905 and several machine-tool producers started to keep up with the demand initiated by the manufacture of oil based engines in the 1920s. Out of 188 establishments surveyed in 1985, thirteen had been in operation before 1940. In 1962, the government decided to establish a machine-tool factory. The Pakistan Machine Tool Factory (PMTF) was started in 1969 in cooperation with OERLIKON and BUHRLE

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(51) H.C. Gandhi: Regional study on machine-tool industry in Asia, the case of India, UNIDO 1990.

(52) According to the Indian presentation to the Working Group Meeting on Cooperation on Production and Application of Machine Tools among Selected Developing Countries, Shangai, May 1989.

(53) Ghulam Kibria: A study of the machine-tool industry, potential of indigeneous capability in the engineering industry of Pakistan, Research Report Series Number 21, National Development Corporation, Karachi, March 1988.

(Switzerland) and BECO (latter called PECO), a private enterprise, was taken over by the public sector in 1972. The production programme of the state enterprises has concentrated on milling machines, turret and precision centre lathes; they have concentrated on the domestic market for high accuracy machines, while the private machine-tool enterprises which were producing less accurate but price competitive machines, served a much larger market.

Pakistan has been producing around 4500 machine tools a year, of which 4300 come from the private sector; domestic production represented 55 per cent of apparent consumption (measured in units) in 1985. The volume of exports while very small (250 units in 1985) is still indicative of the capabilities of the machine-tool industry.

1.3.4 South East Asia

The engineering intensive branches of industry in South East Asia which started to grow on the basis of labour intensive assembly operations, experienced a very dynamic development with a growth rate of 15.4 per cent between 1980 and 1987. South East Asia share of world engineering industry has grown from 8.6 per cent to 17.1 per cent. The electrical industry has been the most dynamic sector in South East Asia. However during the 1980s, the non-electrical and transport equipment sectors also witnessed very strong growths further accentuated in recent years with the impact of the appreciation of the Yen which prompted Japanese enterprises to seek sourcing of inputs in, and transfer technology to South East Asian countries. The development of the engineering industries together with the growth of both domestic and foreign investments in South East Asia have accelerated the demand for machine tools.

In the Republic of Korea[54] (Figure 14) most of the pre-war machine-tool establishments were destroyed during the Korean war; the machine-tool industry was in an embryonic stage before the early 1970s reflecting the generally underdeveloped state of the machinery industry.

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(54) P. Judet: L'industrie de la machine outil en Coree, UNIDO, 1990.

Figure 14: REPUBLIC OF KOREA
Production, import and export

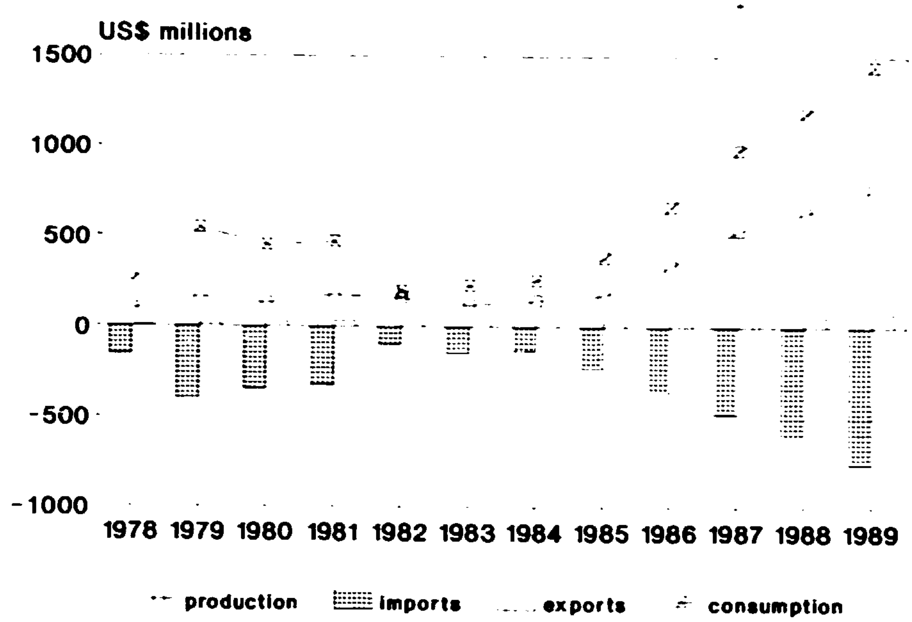
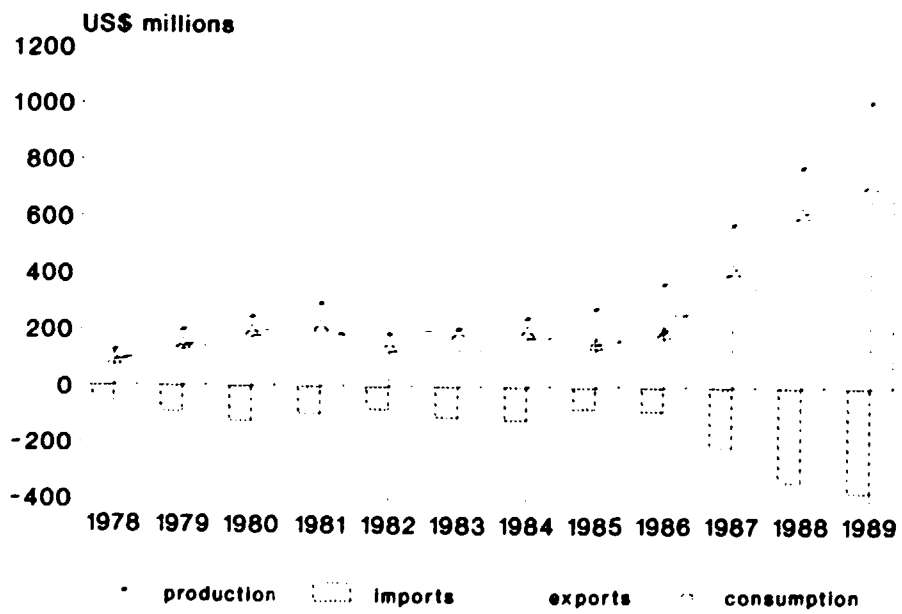


Figure 15: TAIWAN, CHINA
Production, import and export



After the mid-1970s, the machine-tool industry expanded rapidly aided by the Government's long-term development plans which included construction of the Changwon machinery complex. During the fifth Five-Year Economic Development Plan, the Government declared the machine-tool industry as a major exporting sector. Production increased from US$2.6 million to US$53 million in 1980, and US$ 159 million in 1985.

From 1986 to 1989, the Korean industry expanded dramatically and the increase of investment by engineering industries provoked a surge of machine-tool consumption while the increase in wages led to an increased demand for factory automation. The Republic of Korea was the sixth largest machine-tool market in the world in 1988. The domestic production increased from US$200 millions in 1985 to US$600 million in 1988; however, this was insufficient to keep up with the surge of demand. Labour problems, import liberalization and the strengthening of the Won against the dollar were among the factors which led to much of this demand increase to be fulfilled by imports which represented 50 per cent of apparent consumption in 1988 (30 per cent in the late 1970s). While Korean production is mainly domestic market oriented, the price competitiveness generated by the appreciation of the Japanese Yen has led to an increase in exports.

Production of NC machine tools which started in the early 1980s has been increasing rapidly and in 1988 represented 34.9 per cent of metal cutting machine-tool production value.

According to the Korea Machine Tool Manufacturer Association, there are ninety-six manufacturers of machine tools with a total employment of 18,000. The industry is characterized by its concentration; the twelve largest enterprises account for more than fifty per cent of labour. The largest is KIA machine tools, a subsidiary of the KIA group, (motor vehicles) (US$80 million in 1987), followed by WHACHEON (US$70 million) and SAMCHULLY and DAEDONG. Machine-tool production is also carried out within main car manufacturers (HYUNDAI and DAEWOO).

During the 1970s Taiwan, Province of China (Figure 15) transformed itself from an "amateurish"[55] supplier of machine

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[55] Alice H. Amsden: The division of labour is limited by the rate of growth of the market: The Taiwan machine-tool industry in the 1970's, Cambridge Journal of Economics, 1985, 271-284.

tools to South-East Asia into the world's eighth largest exporter and the fourth largest exporter to the United States of America. Production rose from US$ 10 million in 1970 to US$245 million in 1980. After five years of stagnation, the appreciation of the Yen gave another impulse to Taiwanese exports which doubled between 1986 and 1988, while the increase in domestic investment led to a surge in the domestic consumption of machine tools. Taiwan, Province of China is the only developing country running a trade surplus in machine tools. The voluntary export restraint agreement signed with the United States in 1987[56] and the sharp increase of the new Taiwan dollar hampered the exports in 1988 while imports increased by 33 per cent. To overcome these new problems the industry is diversifying its markets and several companies have decided to set up assembly plants in the United States of America.

According to the Taiwan Association of Machine Tool Manufacturers, the industry is made up of around 300 to 500 small companies located around Taichung where there is an extensive subcontractor sector employing 30,000 people. NC machine tools represent around 30 per cent of production in value terms.

In a relatively short period, Singapore has emerged as a significant machine-tool builder. Production started in 1977 and by 1988 the industry sales received US$37 million. The growth of the industry is due to:[57] (i) the presence of international machine tool builders in the country, (ii) the availability of strong support industries such as heat treatment facilities and precision engineering (and of a highly developed electronics industry) and finally (iii) the ease of establishing subcontracting relationships on a regional basis (with Malaysia and to some extent Thailand).

In Indonesia the oil boom in the 1970s financed investment in manufacturing and generated a high demand for machine tools. However, only simple machine tools were produced. A state-owned company was set up in 1983, (PT IMPI) and eleven private companies were approved by the Government.

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(56) In the agreement Taiwan, Province of China agreed to reduce by 10 per cent exports to the United States of America of machining centers, lathes and milling machines.

(57) The Machine-Tool industry in the ASEAN region: options and strategies: Main issue at regional level. UNIDO IS.634.

Unfortunately domestic demand began to decline because of the drop in oil prices. The imports of machine tools which had reached a peak of US$120 million in 1981, fell to US$48 million in 1986, then rose to US$ 110 million in 1987 and 1988. The domestic production remained very small (US$1.3 million in 1988) with lathes being the most commonly produced machine: 241 units were produced locally while 1782 were imported as complete units.[58]

The machine-tool industry in Malaysia is limited to a few manufacturers of wood-working machine tools and simple metal drilling machines. The domestic demand for machine tools is currently estimated at US$ 60 million and is mainly met by imports.

1.3.5 North Africa and Western Asia

The role of oil export revenues in some countries of North Africa and Western Asia has provided the production sector with sufficient means to import capital goods and technology. The oil-based downstream industries have led the industrial growth in this region while the engineering industries sector, especially the non-electrical sector, has recorded a below average growth.

Production capacity in the Arab countries[59] is estimated at 3000 machines per year while production was 2000 in 1987 and heavily concentrated in Algeria, Egypt and Morocco.[60]

In the Islamic Republic of Iran, the TABRIZ MACHINE MANUFACTURING Company, established in 1971, is the first and only manufacturer of machine tools. Production has been limited to lathes, drilling and milling machines. The company had a co-operation agreement with Czechoslovakia and started to produce milling machines with DECKEL (FRG) in 1985. A privately owned company, a spin off from a small engineering research center, has started to manufacture spark erosion machines and has succeeded in exporting some of them. Machine tool production

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(58) Indonesian Commercial Newsletter, October, 1988.

(59) Algeria, Egypt, Iraq, Jordan, Lybya, Morocco, Saudi Arabia, Syria, Tunisia.

(60) Organization for Arab Industrial Development: Le developpement de la machine outil dans le monde arabe, 1987.

covers a small part of the US$100 million domestic market.[61]

In Egypt HELWAN MACHINE TOOL Co. is a state owned company which was established in 1958 and started production in 1962. The machine-tool plant was built on a turnkey basis by the USSR. Designs and production know how were supplied. The plant was equipped with conventional equipment and a Research and Development unit was provided to enable the plant's engineers to design and develop drilling and grinding machines and make some adjustments to lathe designs. A modernization program is underway with the assistance of a German company. The local integration ratio is said to be 85 per cent.[62]

A private civil engineering equipment manufacturer (HAWASH) has diversified into machine-tool production in 1966 to build simple machines for local subcontractors.

In Algeria, the machine-tool industry is dominated by a single national company, Entreprise Nationale de Production de Machine Outil (ENPMO), which started manufacturing in 1977. Cumulated production has been 7,000 machine tools; there are seven product lines: milling machines, boring machines, lathes, hacksaw, shaping machines, sharpening machines and grinders. Current production of ENPMO is US$20 million (500 employees) while the domestic demand is US$233 million. The average level of integration is 78 per cent.[63]

A joint venture for the production of metal cutting and wood working machines has been set up between Morocco and Tunisia, with the participation of a French Machine-tool company. The firm manufactures lathe and milling machines.

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(61) Industrial Development and Renovation Organization of Iran: Development of machine tool industries in Islamic Republic of Iran, note presented to the Shangai Meeting on Machine tools, May 1989.

(62) M.O. Benouali: Rapport pour la reunion sur la cooperation interabe dans le domaine de la machine outil. ONUDI 1990.

(63) Belhadh A. and Chelbi A.: L'industrie de la machine outil en Algerie et en Tunisie. UNIDO 1990 and ENPMO: La Machine Outil en Algerie, situation actuelle et strategie de developpement. May 1989.

1.3.6 Sub-Saharan Africa

In 1984, 72 out of 179 countries which regularly provide detailed industrial data to the United Nations Statistical Office reported zero production of the 145 commodities classified under "manufacture of fabricated metal products, machinery and equipment". In the same year, 51 countries reported that their capital goods production was limited to the manufacture of ten or so products.(64) A large number of these countries belong to the least developed developing countries and are located in Africa. Due to the low level of development of the engineering industries of most African countries, only a few countries have entered into machine-tool industry. In Tanzania, the KILIMANJARO MACHINE TOOL manufacturing company started production in 1983 through importations of inputs from MACHINOEXPORT (Bulgaria). The company produces eight types of conventional machine tools including metal cutting and woodworking lathes, grinding and drilling machines, surface planners, hacksaws and bandsaws and combined woodworking machines. In Nigeria, NIGERIA MACHINE TOOLS has been operating since 1980 in co-operation with HINDUSTAN MACHINE TOOLS of India, while in Zimbabwe and Ethiopia spare parts for machine tools are produced.

2 Machine-tool Consumption

Machine-tool consumption is a rough indicator of a country's rate of industrialization. In 1988 the industrialized countries accounted for 63 per cent of world consumption of machine tools, while the share of centrally planned economies was 28 per cent and that of developing countries 9 per cent, ratios which are close to their overall participation in the engineering industries.

The largest producer countries are also the largest consumer markets. Among the countries whose domestic markets exceeded the US$1 billion benchmark between 1986 and 1988 are the Union of Soviet Socialist Republics, the United States of America, Germany (former F R G), Japan and Italy. The inversion in the ranking as compared to production, for the USA and USSR on the one side and Japan and FRG on the other, reflects the different trade patterns for these countries.

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(64) UNIDO: Industry and development, global report 1988/89, Vienna, p. 121.

2.1 Dynamics of consumption in industrialized economies

The demand for machine tools is closely related to the investment behavior of the engineering industries, where there is a need for technological refitting of existing plants and for the installation of new plant capacity. (Box 7)

Machine-tool consumption, a "hardware" acquisition, used to be closely correlated with manufacturing investment. However due to the technological changes at work, this appears to be less the case in industrialized countries. For example Germany (former F R G) spent less on machine tools in 1988 although manufacturing investment was the highest since 1985; similarly, in the United States of America, machine tool consumption declined from 1987 to 1988 although investment in manufacturing increased. Figure 16 illustrates this trend; it shows the evolution of manufacturing investment (measured in volume) compared to machine-tool consumption measured in constant prices in the case of the United States of America, Germany (former F R G) and Japan.

This evolution is explained by the relative importance of software expenditure as compared to hardware expenditure within capital investment: the dematerialization of capital. The acquisition of new equipment such as numerical control machine tools and flexible manufacturing systems requires increasing expenses in terms of software. The projected fraction of software investment vis a vis hardware investment over time could increase from 10 per cent on new manufacturing investment in 1980 to 20 per cent in 1990 and close to 50 per cent in 2000.(65)

2.2 Machine-tool consumption in developing countries

Table 14 gives consumption figures for some developing countries for the period 1987-1989.

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(65) R.U. Ayres: Technology forecast for CIM in Manufacturing Review, vol 2, no 1, March 1989.

Box 7: Dynamics of consumption

The economic factors explaining the fluctuation of machine-tool demand in industrialized countries have been analyzed by UCIMU which compared machine tool consumption with macro-economic variables in the main industrialized countries, and tested their relationships during the 1980-86 period.

According to its calculation of cyclical elasticity, investment in machine tools during those seven years depended more on conjuncture fluctuations than on economic development. Two explanations can be taken into consideration when explaining the dynamics of machine tool consumption.

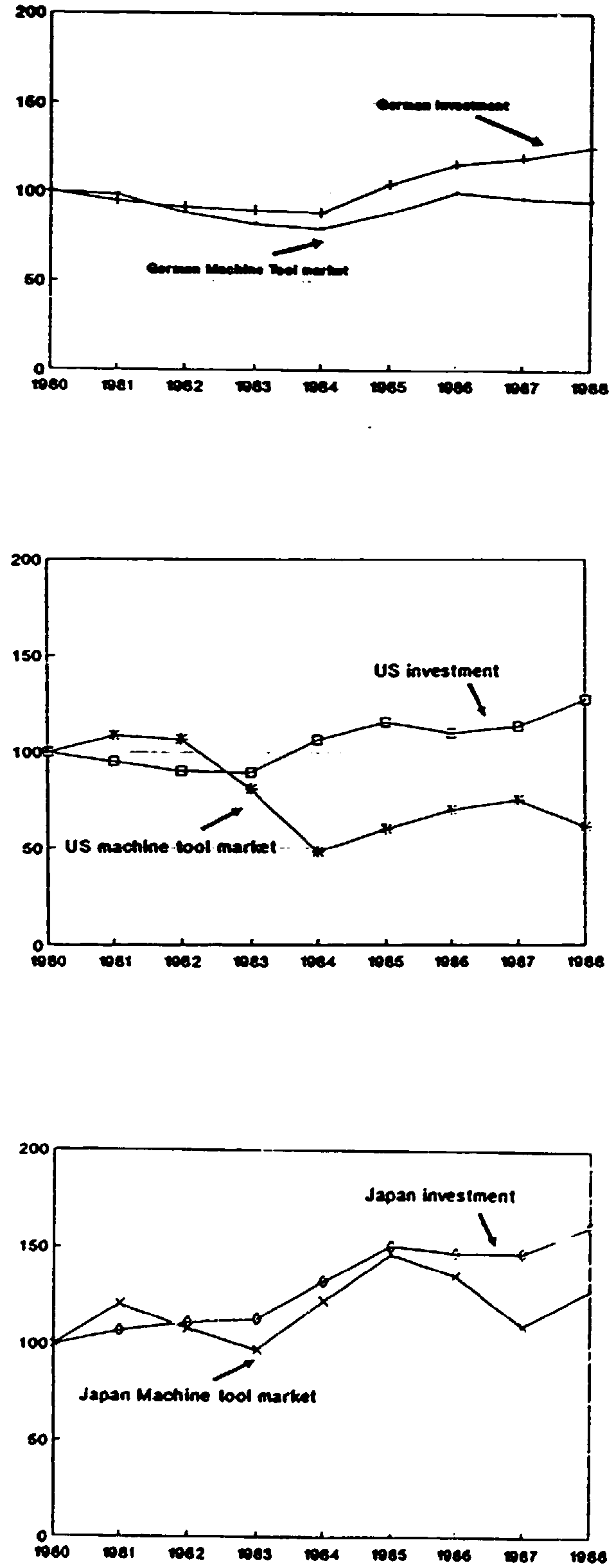
The first assumes that demand for machine tools is the answer to a need for new plant capacity already present in the end users; in that case its growth (or decline) should occur later than the GDP changes.

In a symmetric explanation, one can assume that machine-tool demand foregoes GDP changes as a new plant capacity implies the previous acquisition of the respective capital goods.

The first hypothese corresponds to the conceptual model according to which the investment depends on the level of current profits which determine the possibility of financing and on the level of estimated profits which determine the opportunity to invest; the second is more technical and implies a greater importance to exogeneous elements in investment decisions.

These two hypotheses have been tested in Italy by UCIMU which has inserted lags between GDP and machine tool consumption. The results show stronger correlation coefficient for tthe first hypotheses. From the Italian example, it appears that the consumption of machine tools is closely dependent on expectations in economic trends.

Figure 16: Manufacturing investment and Machine-tools consumption



Source:OECO and American Machinist

Table 14: Developing countries machine tool consumption
(average value in US$ millions for 1987-1989)

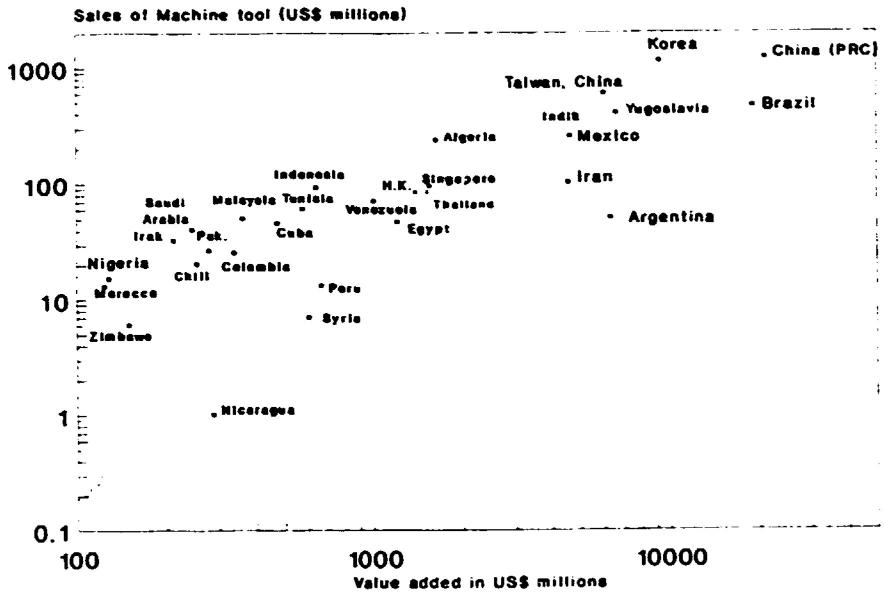
Republic of Korea	1203	Indonesia	69
People's Rep. of China	1132	Malaysia	67
Taiwan, Prov. of China	584	Thailand	59
Brazil	539	Argentina	53
India	388	Venezuela	50
Yugoslavia	336	Portugal	40
Mexico	223	Hong Kong	38
Iran	100		
Singapore	96		
Algeria	93		

Sources: Compiled from American Machinist, UN trade data and national statistics.

There appears to be a clear relationship between the machine tool apparent consumption in a given country and the level of development of its engineering industries (as measured by its value added.[66] Figure 17 illustrates this correlation in the case of twenty developing countries for which engineering value added ranged between US$200 million to US$22 billion. The figure highlights the impact of the economic crisis on Latin America in the case of Brazil and Argentina, where the level of machine tool consumption is not "in line" with the level of development of their engineering industries. One can assume that the domestic market in Brazil "should be" close to US$1 billion (instead of US$590 million) while in Argentina it "should" be US$ 200 million (instead of US$ 36 million). In contrast while the size of machine-tool consumption in the People's Republic of China is in line with its development, the Korean's domestic market, which was the sixth largest in 1988) is extremely large: the need for automation is accelerating investment in machine tools.

(66) Excluding electrical machinery value added because of the bias introduced by the electronics industry which is highly developed in South East Asia and is not a large market for machine tools and as recorded by UNIDO in Industry and Development Global Report 1989/90.

Figure 17: Machine-tools market and engineering industries development(1988)



Value added of engineering industries
(minus electrical ISIC 383)
from UNIDO data base

3 International trade in machine tools

In 1968, one third of world machine-tool production was internationally traded, and in 1988 this ratio rose to 48 per cent. Exporting has made the machine-tool industry a global one, and success in this global business now requires effective exporting. Globalization has been accelerated by reduction in trade barriers, increase in specialization since no country can achieve self sufficiency in an industry so diversified and the efforts by domestic producers to counter the cyclical nature of the industry and look for new markets.

3.1 Trade characteristics

3.1.1 Largest importing and exporting countries

The ten largest importing and exporting countries have been ranked according to their average exports and imports performances over the three years period (1987-1988-1989) in Table 15.

Table 15: The ten largest
Exporting countries - Importing countries
US$ millions, average (1987-1989)

Exporting countries		Importing countries	
Germany (FRG)	4019	United States	2157
Japan	3359	USSR	1924
Switzerland	1553	FRG	1306
Italy	1298	France	935
GDR (former)	1256	Italy	706
United States	766	United Kingdom	700
United Kingdom	605	Canada	646
Taiwan (China)	517	Republic of Korea	618
France	383	People Republic of China	531
Yugoslavia	370	Belgium	395

Table 16: Exports of machine tools 1978-1989
(US$ millions)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Japan	1017	1263	1522	1692	1272	1263	1751	2186	3063	3053	3258	3765
Germany (FRG)	2122	2508	2965	2584	2206	1950	1781	1970	2993	3654	4069	4333
USSR	332	324	302	242	238	245	194	210	288	312	380	380
United States	560	649	785	972	573	406	409	452	590	586	768	945
Italy	596	689	848	795	640	593	558	707	971	1048	1309	1537
Switzerland	653	790	870	740	714	671	672	836	1259	1435	1626	1598
United Kingdom	426	473	675	537	478	319	302	341	395	501	687	627
GDR	548	662	695	674	653	770	744	759	980	1202	1298	1269
France	382	458	516	390	295	295	250	208	308	284	396	470
China (Taiwan)	94	144	178	183	124	132	172	202	261	380	504	667
PRC	20	28	28	30	25	35	38	14	8	93	130	190
Spain	148	211	229	207	165	99	114	151	178	219	260	325
Republic of Korea	5	15	26	32	61	36	22	23	27	37	57	76
Rumania	88	136	145	133	144	114	60	55	52	132	168	188
Yugoslavia	42	54	83	55	136	134	126	143	219	303	403	405
Brazil	20	28	71	74	21	24	20	28	39	23	29	24
Czechoslovakia	246	303	323	310	276	264	251	253	310	330	219	266
Sweden	138	175	181	164	138	114	125	151	164	193	214	225
Canada	53	76	85	99	154	55	119	105	144	64	98	193
Poland	163	190	220	170	53	64	78	71	69	98	119	120
Austria	94	118	131	108	121	127	131	93	161	169	299	363
India	24	20	25	23	20	23	18	20	33	35	34	35
Belgium	99	111	206	119	116	96	104	133	263	294	287	372
Hungary	84	94	94	96	96	97	111	138	138	170	94	96
Bulgaria	15	21	22	201	207	165	140	80	86	85	157	138
Denmark	24	26	39	32	44	37	21	42	52	58	65	62
Netherlands	35	71	93	74	66	105	82	98	121	179	147	156
Singapore	19	24	38	27	22	46	78	84	84	85	30	36
Finland						21	17	23	18	29	40	40
Argentina	12	12	28	19	16	14	2	0	0	16	32	30
Mexico	1	1	4	4	2	2	2	1	3	3	11	10
Portugal	4	5	6	4	3	5	5	7	7	9	10	10
Australia	1	1	1	7	5	4	4	7	4	5	7	8
Hong Kong					4	1	1	1	6	6	0	0
TOTAL	8069	9685	11439	10836	9115	8386	8584	9676	13393	15207	17205	18959

Source: American Machinist

Table 17: Imports of machine tools 1978-1989
(US$ millions)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Japan	120	164	229	216	220	171	139	220	285	265	382	481
Germany (FRG)	462	621	802	616	488	453	467	636	1036	1253	1266	1399
USSR	803	881	988	952	1162	1448	1291	1387	1514	1850	1923	2000
United States	715	1049	1298	1437	1153	946	1356	1738	2252	1969	2058	2445
Italy	194	256	380	300	208	182	183	196	347	566	707	845
Switzerland	124	154	225	189	157	116	130	170	313	360	383	440
United Kingdom	399	600	623	432	409	294	342	614	559	530	732	837
GDR	218	244	257	214	170	111	113	96	157	199	285	299
France	289	371	554	566	479	351	301	358	618	738	971	1097
China (Taiwan)	58	92	125	99	80	110	119	76	85	215	338	374
PRC	65	60	140	125	130	150	140	223	123	494	570	530
Spain	90	91	103	142	176	96	56	59	106	251	312	349
Republic of Korea	156	398	344	324	97	145	135	229	358	486	609	760
Rumania	339	374	317	311	197	125	80	75	71	134	123	115
Yugoslavia	150	193	187	131	140	138	125	69	143	145	154	154
Brazil	226	132	175	124	85	44	40	39	48	49	40	35
Czechoslovakia	170	201	213	168	127	82	74	67	81	85	190	170
Sweden	109	127	185	191	151	120	128	174	229	312	340	310
Canada	228	260	433	557	256	186	256	334	356	528	732	677
Poland	596	498	350	200	120	55	99	86	84	203	233	250
Austria	150	193	187	131	140	138	125	69	151	173	454	529
India	49	46	76	104	151	148	141	162	166	147	145	145
Belgium	113	127	206	139	117	115	127	166	282	321	453	412
Bulgaria	25	23	24	258	262	205	160	145	156	336	123	93
Hungary	113	127	139	127	122	115	93	91	95	124	61	60
Denmark	40	43	51	28	43	40	14	75	114	111	109	99
Netherlands	91	129	160	111	94	122	106	192	326	361	247	251
Singapore	47	84	103	114	107	113	172	143	145	145	40	30
Finland						90	62	70	93	115	111	110
Argentina	60	75	95	70	47	23	33	0	0	38	44	33
Mexico	75	85	310	450	320	110	140	146	202	249	177	203
Portugal	15	39	40	54	50	23	20	23	28	33	34	35
Australia	107	155	155	195	163	113	48	108	134	137	84	70
Hong Kong				4	11	2	5	52	74	75	12	9
SUBTOTAL	6396	7892	9474	9089	7632	6680	6820	8288	10731	12997	14442	15646
OTHERS	1643	1717	1777	1271	1110	1606	1570	927	2496	2984		
TOTAL	8039	9609	11251	10360	8742	8286	8370	9215	13227	15981		

Source: American Machinist

Germany (former F R G) is the leading exporter and Japan has ranked second since 1978. While the share of the United States in total exports has declined, this was more severe in the case of Western Europe. Eastern European countries which mainly traded between themselves also witnessed a decline in their share of exports; Taiwan, Province of China is the eighth largest exporter.
-The largest import market is the USA followed by the USSR and Germany (former F R G). In contrast to other producer countries, Japanese imports remained low so that its share of world imports also remained small. The Republic of Korea and the People's Republic of China rank eighth and ninth respectively among main importer countries. Tables 16 and 17 present the machine tools exports and imports for the 35 main producer countries for the period 1977 to 1989.

3.1.2 Intratrade and market specialization

The machine-tool industry is characterized by a high degree of openness. Trade ratios(67) can be as high as 300 per cent in countries such as Canada or Sweden, while in other industrialized countries (e.g. Germany, Italy, United Kingdom, Switzerland) this ratio is in the 75 to 100 per cent range. Japan is an exception and due to its low level of imports its trade ratio has been less than 50 per cent.

In some Western European countries (Switzerland, Sweden and Germany) exports represent between 60 per cent and 90 per cent of production. The share of imports over apparent consumption is very high in producer countries such as Switzerland and Sweden where the industry is highly specialized in some product lines. The increasing share of imports in domestic consumption of the United States of America contrast with that of Japan where domestic production covers 93 per cent of the apparent consumption.

The evolution of export orientation and of import penetration, shows in several cases that the success in exports is inseparable from a mastery of the domestic market. It is particularly clear in the case of the United States of America and France where the increase in the level of import penetration seems to have gone hand in hand with the loss of exports. The reverse can however be said about Japan where import penetration dropped sharply in a manner parallel to the increase in exports.

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(67) The trade ratio is measured as: import+export/Production.

The combination of export orientation and import penetration for most large producer countries suggests that the machine- tool industry is characterized by a high degree of market specialisations. Table 18 shows the export specialisation in selected metalcutting machine tools of those countries reporting to CECIMO in 1988: a high degree of specialisation is evident as indicated by the following examples:

- in the case Germany (former F R G): lathes, grinding and polishing machines and machining centers account for 65 per cent of exports
- in the case of Japan: lathes (31 per cent), machining centres (28 per cent) and grinding and polishing (12.4 per cent) account for 71 per cent.

Import penetration is lowest in those markets in which domestic producers specialize.

Another way of considering this specialization, is to measure the share of these countries in some specific markets (Table 19):

- Two countries account for 70 per cent of CECIMO exports of gear cutting machine tools: Germany (40 per cent) and Switzerland (29. 7 per cent)
- Two countries (Germany and Switzerland) account for 66 per cent of CECIMO exports of EDM and ECM machines tools

There is also a significant degree of intra-industry trade especially involving control systems and some mechanichal components of machine tools such as chassis.

3.1.3 Trade competitiveness

The analysis of exports and imports flow alone does not show the level of competitiveness of a given country or group of countries. Ranking a country on a given market is based on the balance between its exports and imports as compared to the amount of world trade of the product. For example in the case of North America, exports of machine tools have increased from 1978 to 1989, however the increase of world trade has been far greater such that the share of North America in world trade has decreased from 3.8 per cent to 3 per cent. North American trade balance worsened from 2 per cent to 5 per cent of world trade over the same period.

Table 18: Export specialization for selected metal cutting machine tools in 1988

	Austria	France	Germany (FRG)	U.S.A.	U.K.	Italy	Spain	Sweden	Switzerland	Japan	India	Korea*	China (Taiwan)
Drilling	1%	2%	2%	2%	3%	8%	4%	9%	3%	4%	1%	1%	17%
Milling	21%	18%	13%	6%	11%	14%	44%	5%	12%	4%	11%	4%	14%
Shaping, slotting, sawing	6%	5%	5%	4%	3%	8%	2%	2%	1%	4%	1%	0%	6%
Lathes	43%	24%	24%	13%	33%	16%	19%	15%	16%	31%	36%	65%	26%
Grinding and Polishing	11%	13%	22%	29%	17%	17%	12%	51%	25%	12%	28%	2%	15%
Boring	1%	2%	5%	5%	6%	7%	4%	2%	3%	3%	0%	1%	1%
EDM and ECM	4%	13%	4%	2%	6%	7%	3%	3%	24%	11%	16%	1%	6%
Gear Cutting	0%	0%	5%	8%	1%	2%	0%	0%	7%	1%	7%	0%	0%
Machining centres and transfer	10%	18%	19%	10%	16%	12%	7%	6%	10%	28%	0%	15%	13%
Total Metal cutting	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Total Metal cutting (US$ millions)	183	255	2628	444	535	784	192	124	1310	2453	23	51	423

Table 19: Export market share in selected metal cutting machine tools in 1988

	Austria	France	Germany (FRG)	U.S.A.	U.K.	Italy	Spain	Sweden	Switzerland	Japan	India	Korea*	China (Taiwan)	Total	US$ millions
Drilling	1%	2%	14%	3%	5%	17%	2%	3%	10%	25%	0%	0%	19%	100%	374
Milling	4%	4%	33%	3%	6%	11%	8%	1%	15%	9%	0%	0%	6%	100%	1011
Shaping, slotting, sawing	3%	4%	35%	4%	4%	15%	1%	1%	2%	25%	0%	0%	6%	100%	397
Lathes	3%	3%	27%	3%	8%	6%	2%	1%	9%	33%	0%	1%	5%	100%	2307
Grinding and Polishing	1%	2%	32%	7%	5%	8%	1%	4%	18%	17%	0%	5%	4%	100%	1756
Boring	1%	2%	35%	6%	8%	15%	2%	1%	10%	19%	0%	0%	1%	100%	356
EDM and ECM	1%	4%	13%	1%	4%	6%	1%	0%	36%	31%	0%	3%	3%	100%	882
Gear Cutting	0%	0%	40%	11%	1%	5%	0%	0%	30%	12%	1%	2%	0%	100%	300
Machining centres and transfer	1%	3%	30%	3%	5%	6%	1%	0%	7%	40%	0%	0%	3%	100%	1708
Total Metal cutting	2%	3%	28%	5%	6%	8%	2%	1%	14%	26%	0%	0%	4%	100%	9404
NC metal cutting	2%	3%	31%	2%	5%	4%	2%	1%	10%	37%	0%	5%	2%	100%	5176

Source: Compiled from CECIMO statistics

* Refers to Republic of Korea.

Table 20: Measure of trade competitiveness in the case of North America

	1978	1989
Exports (1)	613	1138
Imports (2)	943	3122
World trade (3)*	16128	37902
	In percent	
Export share (1)/(3)	3.8%	3.0%
Import share (2)/(3)	5.8%	8.2%
Balance	-2.0%	-5.2%

* Taking into account imports by countries which are not reported by American Machinist

Methodology elaborated by the Centre d'Etudes Prospectives et d'Informations Internationales

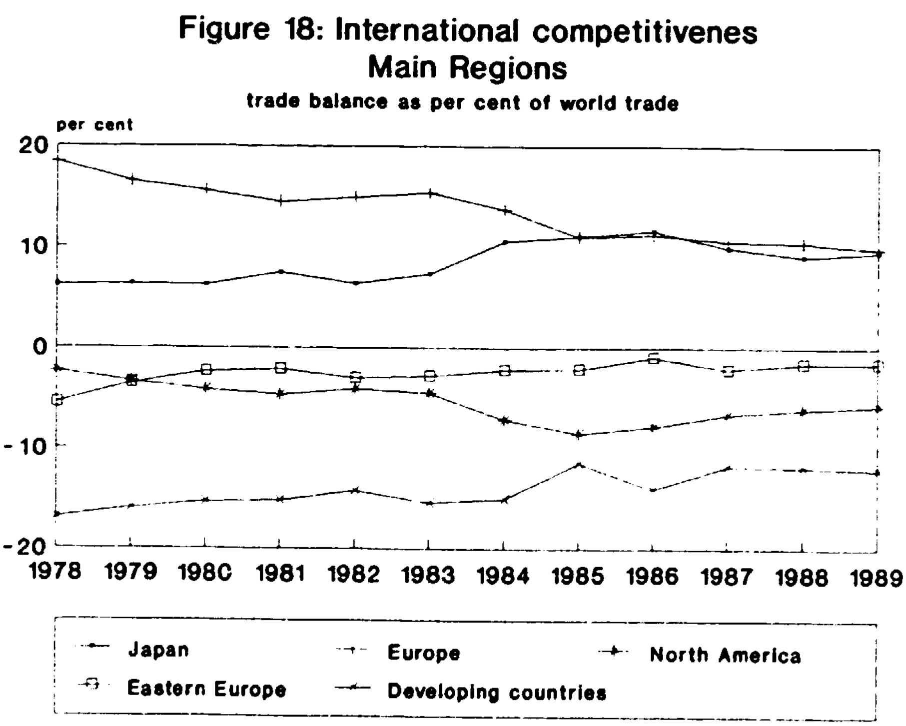

Figure 18 shows the evolution of the trade balance for North America, Western Europe, Eastern Europe (including Soviet Union), Japan and developing countries from 1978 to 1989. It illustrates the erosion of trade competitiveness of West European and North American countries and the improvement of

Japan's competitiveness during the same period. The competitiveness of West Europe is by and large explained by the performances of Germany (former F R G), Switzerland and Italy. The Eastern European countries were not integrated in the international market. This was due to their development strategy and to the fact that Cocom[68] rules did not allow the export of certain NC machine tools judged to have potential military applications.

3.1.4 Developing countries' comparative advantage[69]

The comparative advantage for a given country can be deduced by using three measures:

- -the trade balance of the national industry;
- -the percentage of production exported-which demonstrates international competitiveness even though the industry may be a net importer; and
- -the domestic industry share of the domestic market- which shows the degree of self sufficiency. When coupled with the first measure demonstrates whether this self sufficiency translates into international competitiveness.

Figure 19 positions the main producer developing countries according to these three measures in 1980 and 1989. Five categories of countries can be identified:

(i) Yugoslavia which is a net exporter and its production has achieved a high penetration of the domestic market, is in 1989 the only developing country with all round competitiveness.

(ii) Taiwan, Province of China is also a net exporter, however it is characterized by a lower (but growing from 1980 to 1989) domestic penetration: the growing domestic demand has encouraged imports but the local industry has focused on exports of volume and stalemate products and is a strong niche player (small and medium conventional grinding, machining centres, lathes and drilling machines).

(iii) Three of the developing countries which are analyzed are net importers but with a high domestic market penetration: Brazil, India and the People's Republic of

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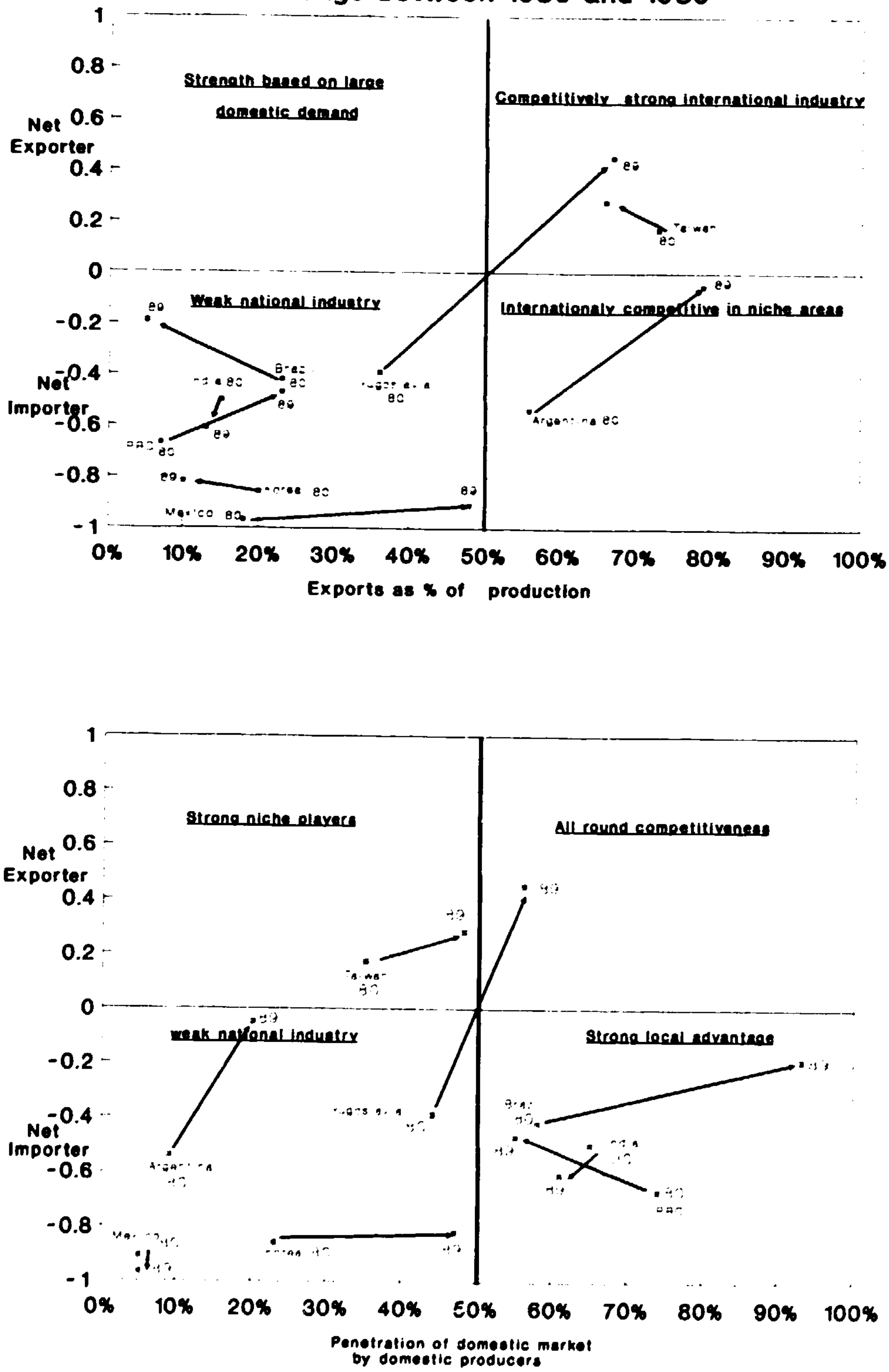
(68) Coordinating Comittee for Multilateral Export Control.

(69) The methodology is adapted to the one elaborated by WS Atkins in Strategic study of the EC machine-tool industry.

Figure 19 Developing countries comparative advantage positions Change between 1980 and 1989



China.

Countries which are net importers and have a low domestic penetration can be further classified according to their export ratio:

(iv) The export ratio of Argentina has grown significantly and this could suggest that this industry with a small domestic market is competitive internationally in a few specialized products.
(v) Mexico and the Republic of Korea are characterized by their low export ratios (and diminishing in the Republic of Korea) and can be thus identified as weak national industries.

However in the Republic of Korea, the national industry is close to providing half of its machine tool needs despite a very rapid growth in the domestic market and is moving into the category of countries with strong local advantages.

3.2 Developing countries imports

Industrialized countries represent the largest import market for machine tools: in 1980 (Table 21) and in 1987 (Table 22), 80 per cent of their exports was directed towards other industrialized countries (including Eastern countries) while 20 per cent was directed to developing countries.(70) Trade in machine tools is often on a regional basis: Eastern European countries directed 83 per cent of their exports to other Eastern European countries; Western European countries directed 57 per cent of their exports to Western Europe and 10 per cent to Eastern Europe.(71)

Exports to developing countries play a very significant role in the case of North America (34 per cent in 1980, 39 per cent in 1987) and increasingly in the case of Japan (from 29

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(70) Export data are compiled from the Economic Commission for Europe and, unlike American Machines export figures, they take into account exports of parts of machine tool (ISTC 736).
(71) There exist close links between German machine tools builders and several machine tools companies of Eastern Europe in term of subcontracting arrangements.

Table 21: Direction of Trade in 1980
(in US$ millions)

from = to:	NORTH AMERICA	JAPAN	WEST EUROPE	EAST EUROPE	TOTAL
NORTH AMERICA	379.40	586.40	885.50	32.10	1883.40
WESTERN EUROPE	372.90	354.50	3904.70	212.70	4844.80
JAPAN	81.80	0	142.90	10.20	234.90
OCEANIA	22.20	40.50	114.50	4.90	182.10
EASTERN EUROPE	39.90	89	1036.40	1221.60	2386.90
DEVELOPING COUNTRIES	482.90	457.30	1451.90	123.30	2515.40
AFRICA	7.90	15.70	253.40	20.10	297.10
LATIN AMERICA	322.60	50.70	594	33.30	1000.60
DEVELOPING ASIA	106.30	369.80	432.40	44.30	952.80
MIDDLE EAST	46.10	21.10	172.10	25.60	264.90
TOTAL	1397.30	1568	7903.80	1668.90	12538

Distribution of industrialized countries exports

to / from =	NORTH AMERICA	JAPAN	WEST EUROPE	EAST EUROPE	
NORTH AMERICA	27.2%	37.4%	11.2%	1.9%	15.0%
WESTERN EUROPE	26.7%	22.6%	49.4%	12.7%	38.6%
JAPAN	5.9%	.0%	1.8%	.6%	1.9%
OCEANIA	1.6%	2.6%	1.4%	.3%	1.5%
EASTERN EUROPE	2.9%	5.7%	13.1%	73.2%	19.0%
DEVELOPING COUNTRIES	34.6%	29.2%	18.4%	7.4%	20.1%
AFRICA	.6%	1.0%	3.2%	1.2%	2.4%
LATIN AMERICA	23.1%	3.2%	7.5%	2.0%	8.0%
DEVELOPING ASIA	7.6%	23.6%	5.5%	2.7%	7.6%
MIDDLE EAST	3.3%	1.3%	2.2%	1.5%	2.1%
	100.0%	100.0%	100.0%	100.0%	100.0%

Origin of imports from industrialized countries

to / from =	NORTH AMERICA	JAPAN	WEST EUROPE	EAST EUROPE	
NORTH AMERICA	20.1%	31.1%	47.0%	1.7%	100.0%
WESTERN EUROPE	7.7%	7.3%	80.6%	4.4%	100.0%
JAPAN	34.8%	.0%	60.8%	4.3%	100.0%
OCEANIA	12.2%	22.2%	62.9%	2.7%	100.0%
EASTERN EUROPE	1.7%	3.7%	43.4%	51.2%	100.0%
DEVELOPING COUNTRIES	19.2%	18.2%	57.7%	4.9%	100.0%
AFRICA	2.7%	5.3%	85.3%	6.8%	100.0%
LATIN AMERICA	32.2%	5.1%	59.4%	3.3%	100.0%
DEVELOPING ASIA	11.2%	38.8%	45.4%	4.6%	100.0%
MIDDLE EAST	17.4%	8.0%	65.0%	9.7%	100.0%
TOTAL	11.1%	12.5%	63.0%	13.3%	100.0%

Table 22: Direction of Trade in 1987
(in US$ millions)

from: to	NORTH AMERICA	JAPAN	WESTERN EUROP	EASTERN EUR	TOTAL
NORTH AMERICA	336	1269	1203	14	2822
WESTERN EUROPE	328	72[illegible]	5681	265	7003
JAPAN	89	0	171	17	277
OCEANIA	28	58	102	2	189
EASTERN EUROPE	17	97	1081	2468	3664
DEVELOPING COUNTRIES	517	1137	1592	207	3453
AFRICA *	6	10	216	35	267
LATIN AMERICA	242	50	303	51	646
DEVELOPING ASIA	251	1047	772	86	2157
MIDDLE EAST	17	30	301	35	384
	1320	3299	9883	2971	17474

Distribution of industrialized countries exports

to / from =	NORTH AMERICA	JAPAN	WEST.EUROPE	EAST EUR	
NORTH AMERICA	25.4%	38.5%	12.2%	.5%	16.1%
WESTERN EUROPE	24.9%	22.1%	57.5%	8.9%	40.1%
JAPAN	6.7%	.0%	1.7%	.6%	1.6%
OCEANIA	2.1%	1.7%	1.0%	.1%	1.1%
EASTERN EUROPE	1.3%	3.0%	10.9%	83.0%	21.0%
DEVELOPING COUNTRIES	39.1%	34.5%	16.1%	7.0%	19.8%
AFRICA	.5%	.3%	2.2%	1.2%	1.5%
LATIN AMERICA	18.4%	1.5%	3.1%	1.7%	3.7%
DEVELOPING ASIA	19.0%	31.7%	7.8%	2.9%	12.3%
MIDDLE EAST	1.3%	.9%	3.0%	1.2%	2.2%
	100.0%	100.0%	100.0%	100.0%	100.0%

Origin of imports from industrialized countries

to / from =	NORTH AMERICA	JAPAN	WEST.EUROPE	EAST EUROPE	
NORTH AMERICA	11.9%	45.0%	42.6%	.5%	100.0%
WESTERN EUROPE	4.7%	10.4%	81.1%	3.8%	100.0%
JAPAN	32.2%	.0%	61.8%	6.0%	100.0%
OCEANIA	14.6%	30.5%	53.9%	1.0%	100.0%
EASTERN EUROPE	.5%	2.7%	29.5%	67.4%	100.0%
DEVELOPING COUNTRIES	15.0%	32.9%	46.1%	6.0%	100.0%
AFRICA	2.3%	3.6%	81.1%	13.0%	100.0%
LATIN AMERICA	37.5%	7.8%	46.9%	7.8%	100.0%
DEVELOPING ASIA	11.6%	48.6%	35.8%	4.0%	100.0%
MIDDLE EAST	4.5%	7.8%	78.5%	9.2%	100.0%
TOTAL	7.6%	18.9%	56.6%	17.0%	100.0%

Compiled from the Bulletin of Statistics on World Trade in Engineering Products for 1987, published by the Economic Commission for Europe (1989)
* Excluding South Africa

per cent to 34.5 per cent). The proportion of Western Europe machine tool exports to developing countries has decreased from 18 per cent to 16 per cent, the same evolution has happened in the case of Eastern Europe (from 7.4 per cent to 7.0 per cent).

Machine-tool imports statistics of 73 developing countries between 1980 and 1987[72] show that (Table 23 and Figure 20) the average value of imports of machine tools over the 1980-87 period has been

- less than US$ 1 million for 11 developing countries
- between US$1 million and US$ 10 millions for 32 developing countries
- between US$ 10 millions and US$ 100 millions for 24 developing countries
- only seven developing countries[73] have imports (and consumption) superior to US$ 100 million

For most of developing countries machine-tool imports represent less than 1 per cent of their total engineering products imports, and can hardly be considered as a constraint.

While the global share of developing countries in industrialized countries exports has remained constant in 1980 and 1987, there has been a significant change between regions. The share of Africa has declined from 2.4 per cent to 1.5 per cent and the imports of Latin American countries have been deeply affected: they represented 8 per cent of exports from industrialized countries in 1980 and 3.7 per cent in 1987. In contrast, the share of developing Asia has increased from 7.6 per cent to 12.3 per cent representing 60 per cent of developing countries imports in 1987. Western Europe remained the largest supplier of machine tools to developing countries,[74] and Japan was second in 1987. While imports from developing Asian countries are relatively diversified, this is not usually the case for

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(72) These data differ from American Machinist data: (i) UN statistics take into account import of spare parts (ii) they do not take into account developing countries imports of machine tools coming from other developing countries.

(73) Including Taiwan, Province of China which is not recorded in the United Nations Statistics.

(74) ECE statistics do not take into account export of developing countries to other developing countries, however this South trade remains extremely limited in its amount.

Table 23: Imports* of machine tools by developing countries 1980 - 1988 (in millions of US dollars)

	1980	1981	1982	1983	1984	1985	1986	1987	1988
AFRICA **	281	308	306	246	236	277	345	269	182
Algeria	61	62	73	52	64	84	82	63	44
Angola	3	4	1	1	2	5	3	5	1
Burundi	0	1	1	0	1	1	1	1	1
CEUCA	5	6	8	7	6	5	7	5	4
East Africa	19	12	9	11	9	8	10	12	8
Egypt	52	48	51	57	63	64	56	47	29
Ethiopia	1	2	2	3	2	2	9	13	6
Ghana	4	3	7	1	1	2	3	3	2
Guinea	1	1	1	0	1	1	1	1	1
Liberia	1	1	1	1	1	1	1	1	0
Lybia	15	31	18	26	22	20	36	21	25
Madagascar	3	2	2	2	1	1	1	1	0
Malawi	1	0	0	0	0	1	1	0	0
Morocco	10	13	15	15	9	12	12	13	13
Mozambique	2	2	2	1	1	1	4	7	1
Nigeria	48	74	69	29	16	45	72	33	6
Sudan	4	5	5	3	2	2	3	3	2
Togo	1	1	0	0	0	0	1	1	1
Tunisia	17	15	16	15	19	11	18	13	14
Zaire	4	2	4	2	4	3	4	5	4
Zambia	7	5	2	2	2	1	2	3	3
Zimbabwe	1	4	4	3	1	2	7	4	8
Other Africa	20	14	15	14	11	9	14	17	10
LATIN AMERICA	1003	1017	816	506	416	442	556	664	345
Argentina	113	87	52	28	38	30	32	42	39
Bolivia	5	4	1	0	1	1	2	2	0
Brazil	257	171	122	71	48	78	120	203	104
Chile	19	18	12	5	9	8	12	19	8
Colombia	35	26	25	15	15	14	18	23	12
Costa Rica	3	2	1	2	3	3	3	3	1
Cuba	18	12	19	49	23	22	55	37	20
Dominican Republic	5	4	3	2	3	4	7	3	4
Ecuador	9	11	8	4	5	5	10	9	5
El Salvador	1	1	1	1	1	1	2	2	1
Guatemala	3	2	2	1	3	2	2	3	2
Haiti	1	1	1	1	1	1	1	0	0
Honduras	2	2	1	1	2	2	1	2	1
Mexico	403	562	450	273	204	205	225	213	66
Nicaragua	0	1	3	3	10	5	1	1	0
Panama	2	2	3	2	2	2	2	2	1

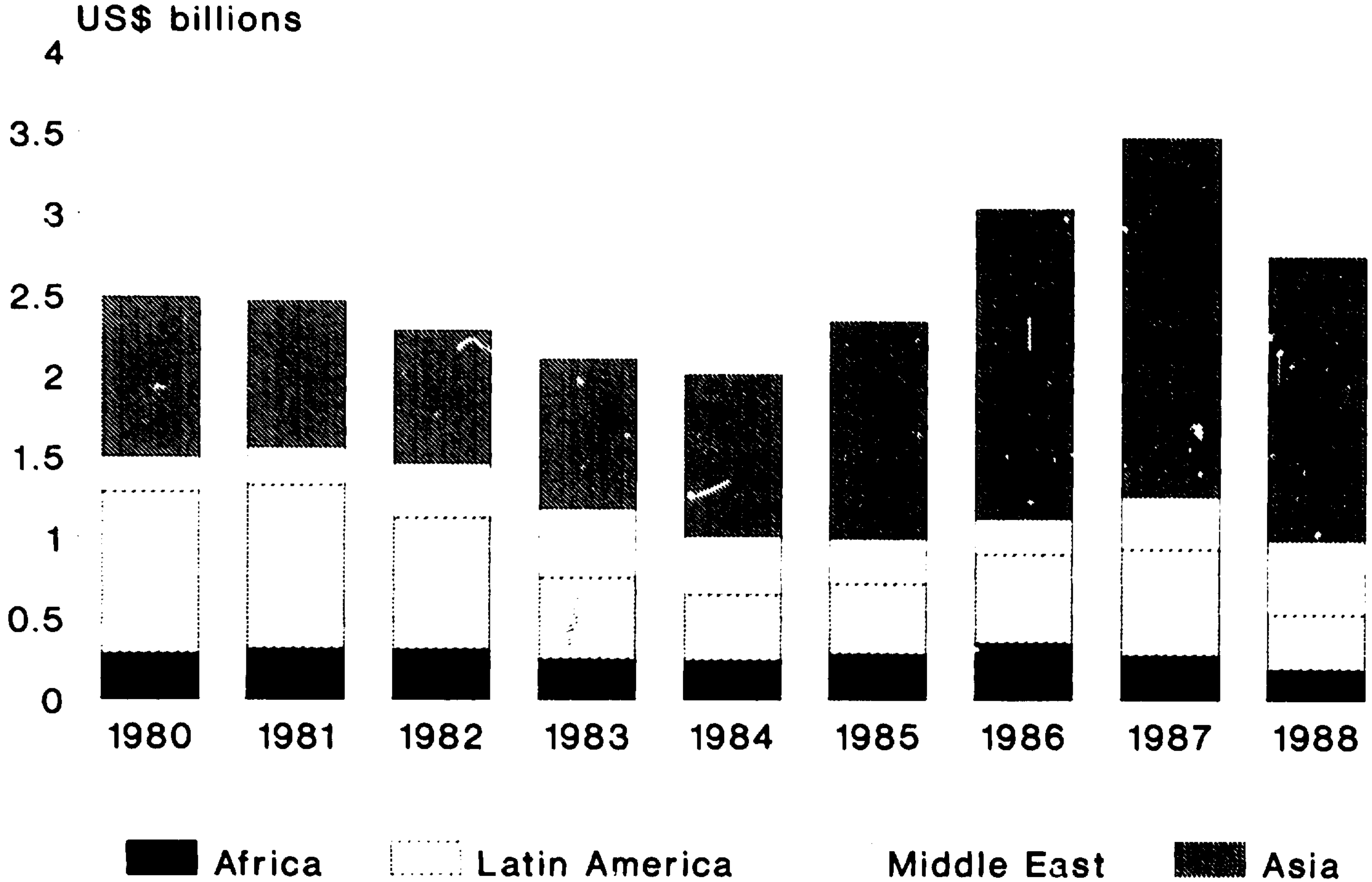
Paraquay	1	2	0	0	0	0	0	1	4
Peru	17	17	18	8	6	10	8	13	4
Suriname	1	1	1	1	0	0	0	0	0
Uruguay	5	3	2	0	0	1	1	2	1
Venezuela	88	72	73	27	34	44	48	76	65
West Indies	11	11	15	8	6	4	5	5	3
Other Latin America	5	7	4	3	3	2	3	4	4
MIDDLE EAST	216	233	336	427	355	273	219	321	455
Bahrain	3	2	2	3	7	8	1	1	1
Iran	23	27	51	156	158	138	98	209	203
Iraq	58	64	137	120	58	33	27	50	201
Jordan	8	10	9	8	5	7	6	8	4
Kuwait	9	8	11	10	8	10	7	4	3
Lebanon	13	8	6	7	5	1	3	1	4
Saudi Arabia	57	85	81	96	76	45	45	33	28
Syrian	27	11	15	10	20	13	9	5	2
Other	19	19	23	18	18	18	22	10	10
DEVELOPING ASIA	986	904	822	924	999	1342	1908	2210	1758
Afganisthan	0	0	0	2	0	0	1	5	0
Bangladesh	6	5	4	4	2	4	4	5	2
Burma	13	4	5	5	5	11	4	2	5
China	143	95	65	93	124	397	751	532	313
Democratic Kampuchea	0	0	0	0	0	0	0	1	0
Hong Kong	38	42	27	27	37	54	70	36	80
India	145	169	197	170	164	175	239	233	155
Indonesia	39	63	56	53	58	54	51	92	53
Korea (Democratic R)	37	14	15	32	15	9	7	16	10
Korea (Republic of)	176	99	84	170	183	276	404	623	507
Laos	0	0	0	0	0	0	1	1	0
Malaysia	48	53	49	56	81	60	32	57	41
Mongolia	1	0	0	2	0	0	10	10	0
Pakistan	14	15	24	26	23	32	28	26	28
Philippines	27	26	28	18	13	9	9	17	11
Singapore	97	117	115	84	102	89	93	151	135
Sri Lanka	2	5	2	2	3	4	4	6	4
Thailand	34	36	27	38	62	66	38	83	148
Vietnam	10	4	3	13	1	1	19	10	1
Others	155	156	122	128	127	102	142	255	266

* Import data may differ from American Machinist data recorded in previous Tables since they take into consideration imports of parts for machine-tools.

** Excluding South Africa.

Source: Compiled from various issues of the Statistics on World Trade in Engineering Products United Nations.

Figure 20: Imports of machine-tools (and parts) by developing countries



Source: compiled from E.C.E. statistics

African and Middle Eastern countries which import mainly from Europe, or for Latin American countries which import from the United States and Europe.

4 International investments

In contrast to its trade orientation, the internationalization of capital in the machine-tool industry has so far been limited and most foreign investments were made in industrialized countries. Proximity to the market and maintenance factors[75] were among the reasons explaining these investment trends. However the machine-tool industry is increasingly following the general trend towards globalisation of production and research.

Leading American companies have invested in Europe for several years. CINCINATI MILACRON produce one fifth of its total sales in plants located in Austria, France, United Kingdom and the Netherlands. Among other American companies with German, British or French subsidiaries are LITTON, TEXTRON, TELEDYNE LANDIS, and INGERSOLL.[76] European firms have been investing in the United States, TRUMPF, a leading German firm, has recently opened a plant in Connecticut.

Overseas production by Japanese machine-tool manufacturers has been a competitive strategy which followed their export drive.[77] Japan increased its US and European presence in the last three years to serve the newly installed Japanese auto manufacturers: data figures from the Japanese Economic Institute indicate that the number of Japanese machine-tool makers in the United States has grown from 17 to 36 between 1987 and 1990.[78] The United States is not only a large capital goods market, it is also a low cost location for production of high value-added products, with US labour costs lower than those in Germany and Japan. Japanese firms in the United States have two areas of cost advantage: they build some critical parts in Japan in

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(75) To be able to repair a breakdown in a client company abroad implies having skilled staff and a large stock of spares.

(76) Which has acquired WALDRICH COBERG and WALDRICH SIEGEN and BOEHLE in the Federal Republic of Germany.

(77) In 1974 YAMAZAKI established assembly facilities in the US, it was followed by HITACHI SEIKI in 1980 and IKEGAI.

(78) International Herald Tribune: UN Machine tool makers look abroad, 1 February 1990.

extremely large volumes for their world-wide operations and have efficient US plants with state-of-the-art equipment for part making.[(79)] Imported machines and those made in foreign subsidiaries may well provide two thirds of US consumption in the 1990s.

FANUC has plants in Europe and in the United States and has entered into a joint venture with General Electric to mass produce 32bit NC control devices.[(80)] AMADA SOIKE has subsidiaries in France, Australia and (through SOINOIKE) in the United States. TOYODA is present in France and the United States, YAMAZAKI MAZAK Corp has manufacturing plants in the United Kingdom and the United States[(81)] and is investing in France and Singapore. OKUMA has a subsidiary in the United States. LEBLOND MAKINO is claimed to be the largest Japanese subsidiary in the United States.

Foreign investment in developing countries has been limited to a few cases in Latin America, India and Singapore. Germany (former F R G) has been a forerunner in seeking to enter into joint ventures in Latin America where during the 1970s, 15 German firms installed themselves in that region. There have been cases of subcontracting arrangements between Japan and Taiwan Province of China, the Japanese firms having completely withdrawn from manufacture of conventional products.

In the coming years there could be an increasing number of foreign investment made by Japanese machine tool manufacturers. According to some projections, Japanese firms could delocalize as much as 50 per cent of their machine-tool production. While a significant amount will be invested in the United States and Europe, this trend may favor investment in some developing

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(79) Interview of Monarch Machine-tool President, Asia Wall Street Journal, January, 1990 23.

(80) Machinery and Mechanical Engineering, 18 January 1989.

(81) MAZAK is expanding its facilities in Kentucky with the installation of three new flexible manufacturing systems which will make parts totally unattended Asia Wall Street Journal, 23 January, 1990.

countries especially those in Asia.[82]

As in the case of the electronics industry, there are some examples of "reverse foreign direct investment",[83] involving the take-over by a developing country's firm of an industrialized country's firm. The objective is rapid and full access to NC technology.

5. Forecast of world machine-tool markets

According to recent forecast,[84] the world machine-tool industry faces a continued period of dynamic expansion at an annual growth rate of 4 per cent in real terms world wide from 1988 to 1995. By the end of this period growth rates are expected to decline with no recession taking place.

The strongest growth (Table 24) in demand could occur in Japan and in the developing countries while the prospects in the United States of America, USSR and Eastern European countries are bleaker. High import increase will take place in Japan, EEC countries and developing countries (5.2 per cent).

The production forecasts appear bright for the machine-tool producers in the newly industrialized countries, Japan and the European Free Trade Area.

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(82) HITACHI plans to shift production of machine tool motors from Japan to Thailand in a cost cutting move. Hitachi Industrial Technology in Thailand started manufacturing 200 000 single phase motors a year which will be exported in Asia Wall Street Journal, 31 March 1990.

(83) O'Brien, Recent developments in the Machine Tool industry: the prospects for foreign direct investment with particular reference to Asian developing countries, UNIDO PPD.53 10 September 1987.

(84) Strategic study for EC industry. Forecast was made before the Gulf crisis and did not take into consideration the likelihood of a recession in main industrialized countries.

Table 24: World machine-tool markets forecast 1988-1995

World Domestic Demand

	Ecu billions*	annual growth rate	
	1988	1980-88	1988-95
EEC	7.70	2.10	5.20
EFTA	1.57	5.10	4.90
CMEA	7.17	1.30	1.90
United States	2.79	-2.40	4.40
Japan	4.22	7.90	5.80
Developing countries	2.09	9.20	5.30

World Import

	Ecu billions	annual growth rate	
	1988	1980-88	1988-95
EEC	1.82	6	6.70
EFTA	1.05	6.80	4.10
CMEA	1.39	-1.90	3.70
United States	1.46	6.80	6.10
Japan	.32	6.10	11.40
Developing countries	1.17	4.70	5.20

World Export

	Ecu billions	annual growth rate	
	1988	1980-88	1988-95
EEC	3.51	-.60	4.30
EFTA	1.49	7.20	5.50
CMEA	.17	-3.40	6.10
United States	.63	-2.60	2.70
Japan	2.59	10.60	6.80
Newly Industrialized c	.26	2.50	6.10
WORLD	8.65	3.50	4.90

World Production

	Ecu billions	annual growth rate	
	1988	1980-88	1988-95
EEC	9.39	.50	4.50
EFTA	2.01	4	5.10
CMEA	5.95	1.80	1.60
United States	1.96	-6.40	2.50
Japan	6.49	9	5.30
Newly Industrialized c	1.18	2.50	5.50
WORLD	26.98	2.50	4

* 1985 prices

Source: Strategic study on EC machine tool sector
Brussels June 1990.

CHAPTER III: TECHNOLOGICAL CHANGES

Among the new technologies, microelectronics is of central importance for the machine-tool industry while the impact of new materials is also beginning to be felt. The introduction in the mid-seventies of the microprocessor, a complete programmable integrated circuit, to the factory floor has been the major technological breakthrough in the capital goods industry. It occured after a long period of relative stability with regard to production technology.[1] Machine tools are "at the core of technological diffusion"; as such, changes which affect them have to be considered in the broader context of changes in technological paradigm.

After a brief introduction to the paradigm of flexible specialisation, this chapter will focus on the diffusion of numerical controlled machine tools and flexible manufacturing systems (1).

1 From mass production to flexible specialisation and flexible mass production

A paradigm[2] involves a new set of best practice rules and customs, new approaches on how to relate technology to market problems, new solutions to established problems. Several authors have discussed the impact linked to the diffusion of microelectronics.

1.1 A new paradigm

Stressing the limits of mass production -fragmentation of work, use of dedicated machinery, complete job specification and removal of worker control- it was foreseen in the late 1970s that the prospect for overcoming those limits lay in flexible

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(1) UNCTAD: The diffusion of electronics technology in the capital goods sector in the industrialized countries, Geneva, 1985.

(2) The concept of paradigm used by Kuhn has been extended to technology by Giovanni Dosi in "Sources, procedures and micro-economic effects of innovation", Journal of Economic Literature, September 1988, vol XXVI number 3. Previous technological paradigms include: the internal combustion engine, oil-based synthetics chemistry.

specialization:[3] the modern analogue to craft productive organizations which had predominated in the early 19th century. The major difference between mass and craft production is the flexibility of productive resources. Craft productive resources, both labour and capital are capable of shifting across a variety of different uses and hence of accomodating a range of variations in economic conditions. In terms of technological dynamicism, however, the difference appears to be that craft production, or flexible specialization, generates growth by "stretching" existing resources so that they can do more or different things. Flexible specialization[4] does not depend upon new technologies; however the possibilities opened by electronic- based automation technologies "*will be seen in retrospect as a turning point in the history of mechanization*". Others[5] have discussed the transition from the previous techno-economic paradigm, based on low-cost oil, energy intensive materials, continuous flow process or the assembly line for the mass production of identical products to the new techno-economic paradigm based on microelectronics and associated information technologies.

The main features of this technological paradigm are the trend towards "flexibility" associated with "information intensity". (see Box 8). Since the Industrial Revolution, increased mechanization has been accompanied by increased exploitation of economies of scale and higher efficiency of production was generally associated with "Taylorist" and

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(3) Piore and Sabel: The second industrial divide: possibilities for prosperity, Basic Books, 1984: "*The first industrial divide came in the nineteen century when the emergence of the mass production technologies-initialy in Great Britain- then in the United States- limited the growth of less rigid manufacturing technologies which existed primarily in various regions of Western Europe. These less rigid manufacturing technologies were craft systems (..) skilled workers used sophisticated general purpose machinery to turn out a wide and constantly changing assortment of goods for large but constantly shifting markets" (page 5).*

(4) One can take for example the flexibility of the Prato industries in Italy.

(5) See Carlotta Perez, Microelectronics, long waves and world structural changes: new perspective for developing countries, World Development vol 13 No 3 1985 also M. Humbert: Global study on electronics industry, UNIDO, ID/WG.478/2, 1988.

Box 8: Flexibility

Flexibility is the most important key word in the case of machine-tools; it has become one of the main requirements in manufacturing technology in response to several factors: increased international competition, market demand for greater quality, more variety in product specification, improved delivery times and shorter product life cycle.

The concept of flexibility is imprecise and has a number of dimensions which require accurate definition:

Machine flexibility: the ease with which the machines in the system can be reset with respect to fixtures, positioning, etc.
Process flexibility: the ability to produce a set of parts type, using different materials in several ways
Product flexibility: the ability to change over to production of a new product quickly and economically
Routing flexibility: the ability to re-route work pieces in the event of a breakdown in different parts
Volume flexibility: the ability to operate at different production volumes
Expansion flexibility: the ability to expand a system as required
Operation flexibility: the ability to interchange the order of operations
Production flexibility: the range of parts type that a system can produce

Sources: Economic Commission for Europe: Recent trends in flexible manufacturing New York 1986

"Fordist"[6] principles of organization. They are correlated with a very high degree of inflexibility in terms of acceptable production runs and mixes. Ford's epigram, "the customer can have any color as long as it's black" meant that flexibility costed time and money. To cope with increasing uncertainty about consumers' demands meant short production runs and very high costs. Automated equipment had to be dedicated to a specific task and up to the seventies it was either feasible for mass production of homogeneous products or for production of prototypes by highly skilled workers using flexible machines. Automation was said to be restricted to the three "A's": aerospace, armaments and automotive (where its best illustration is the transfer line).

Flexible automation allows a new compromise between flexibility and economies of scale. While economies of scale were gained because the cost of producing a single unit declines as volume of production increases, economies of scope are gained in the volume production of a set of differentiated goods[7] and they are created by standardizing processes to manufacture a variety of products.[8] Economies of scope can been interpretated as the ability to convert fixed capital from one purpose to another.[9]

As compared to classical (electromechanical) automation, numerically controlled machine tools, flexible manufacturing

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(6) Taylorism designates a type of work organization described by Fred. W. Taylor an American consultant engineer. It results in separating the tasks of work design and work execution on machine. While the concept of Taylorism is closely associated with the management of people, the concept of Fordism stresses the market and production strategy associated to Taylorism: it means the organization of mass production of standardized products for a relatively homogeneous product.

(7) J. D. Goldhar, M. Jelinek: Plan for economies of scope <u>Harvard Business Review</u> 61, November-December 1983, page 141.

(8) Economies of scope (known as the Baumol effect) exist when a firm which produces simultaneously two products is able to produce them at a lower cost than two separate firms producing separately each one of these product. This will not be the case if the economies of scale gained in the production of each one of the products are larger than the economies of scope.

(9) R.U. Ayres: <u>Computer Integrated Manufacturing: Hypotheses</u>, Opening Address IIASA CIM Conference, Vienna, July 1990.

systems and robots allow a much greater flexibility in terms of (i) accepted variance of throughputs (defined in number of cost-effectively produced homogeneous items per unit of time (ii) acceptable variances in output varieties and (iii) minimum scale of production.[10] With the advent of flexible automation, plant size tends to become more independent of market size.

The interpretation of recent shifts in manufacturing practices from mass production to flexible specialisation is far from being uncontroversial. Strategies built on economies of scope could win over strategies built on economies of scale if and only if there will not exist any more products whose demand is sufficiently growing and stable.[11] If this is not the case, for products whose demand is growing and stable, the advantage of scale do not disappear. As it has been shown in the case of Italy, while small firms are now able to compete in markets where economies of scale used to be a barrier to entry, large plants which realize flexibility are also able to cater for several relatively small markets.[12] New technologies, which substitute capital for labour, create new large scale economies and therefore may extend the role of large companies.[13] This caveat applies to the machine tool industry. The historical industry fragmentation was relatively functional as long as there were few economies of scope or scale to be gained from broader product lines. In the absence of modular design and flexible automation, production economies were gained in producing standard models

(10) It should be borne in mind that flexibility rests on organization: identical machines can be used in a rigid or flexible way.

(11) The implicit hypothesis of the model of flexible specialization is that the demand should be both unstable and segmented. In that case the strategies based on differentiation will gain over strategies built on economies of scale. B. Coriat: L'atelier et le robot, Christian Bourges Editeur, Paris 1990, page 163-165.

(12) In its new plant in Ozaka, Mitsubishi has five different models coming off the same line, a degree of flexibility seemingly unmatchable elsewhere, (Financial Times World car industry, September 13 1989.

(13) Gian Maria Gros-Pietro and Secondo Rolfo: Flexible automation and firm size: some empirical evidence on the Italian case, Technovation 9 (1989), page 493-503.

which had long product life cycles; this strategy [14] which worked against product changes, has become increasingly dysfunctional with the diffusion of new technologies.

In fact, as pointed out by Piore, the economic revival in industrialized countries during the 1980s has involved both kinds of growth: organisations devoted to flexible specialization have done well, but there has been a revival of mass production organizations which have done much better than in earlier period with a a shift to flexible mass production.[15]

1.2 New factors of competitiveness

The trend towards more flexibility is also to be considered in the context of the changes affecting market demand in industrialized countries. During the 1950s, in the context of relative scarcity, price was the most important criterion for any consumer product and entreprises mass-produced goods looking for the cheapest labour costs; in the 1970s, quality became a criterion as important as price, and in the 1980s consumers have demanded quality products more tailored to their individual needs and tastes. The era of mass production of undifferentiated products has come to an end; the major challenge wil be to combine mass production and specificity.

This demand pressure which was first felt in the consumer electronics market, has developed in the car industry[16] and has called for new production technologies (such as modular manufacturing methods) borrowed from the electronics and aerospace industries.[17] Corporations which produce customized goods aimed at market niches, have to be flexible enough to

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(14) According to C.F. Pratten (Economies of scale for machine tool production, The Journal of Industrial Economics, vol 19, 1970-71 pp 148-165) the major economies of scale in British machine tool industry derived from large cumulative output of a single model: this reinforced small firm size and narrow product lines.

(15) M.Piore: The economic revival of the 1990's: Technology, organisational structure and competitive strategy Technology and Competitiveness Conference Paris 24th-27th June 1990.

(16) Ted Kumpe, Piet T.Bolwijn: Manufacturing the new case for vertical integration Harvard Business Review, March-April 1988.

(17) The Economist: "The arrival of haute carture", 29 July 1989.

increase their production in those segments in which demand proves high: they need equipment that can produce economically in small batches in order to reduce work in progress, minimize inventories and allow consumer demand to be met in days instead of months. In some markets, there is a growing "time based competition" between manufacturers: consumers will pay more for the privilege of speed.[18]

The consequences of these changes go beyond a retooling of manufacturing facilities: in fact, flexibility can often be achieved through organizational innovation. In order to face up to these new challenges manufacturing companies are reorganizing their production processes under "just-in-time" (JIT) principles through such techniques as "set-up time reduction" or "Kan-Ban"[19] procedures. (Box 9) Developed originally in the 1960s as a way to reduce inventories, JIT quickly evolved into an overall system for eliminating waste and maintaining high levels of reliability and quality in the total production process. Suppliers are grouped more closely around the final assembly plant so that the parts they supply arrive literally minutes before they are needed. In this way the final producer is spared the costs of inventory and defective components are spotted immediately. While in the traditional organization, one produces goods and sells them, in Kan-Ban the objective is to produce goods which have been already sold: this illustrates the primacy of marketing imperatives on production. The essential elements of the Just-In-Time concept are that goods should be bought or produced in exactly the quantities which are needed and they should be delivered when they are needed.[20]

1.3 The social impact of flexible automation

While mechanization had mainly been concerned with the decrease of labour costs per unit, flexible automation is aimed at reducing all items that make up total production cost, i.e. capital cost through reduction of work in progress and finished

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(18) The Economist: "About time", August 11, 1990.

(19) Named for the routing slip attached to each piece in transit.

(20) U. Arnold, K. Bernard: Just-in-Time: some marketing issues raised by a popular concept in production and distribution, Technovation, 9 (1989) page 401-431.

Box 9: Just-in-Time, Kan-Ban and Kan-Ban plus alpha effect

In manufacturing there is a conflict between two objectives: holding down set-up time for the machines by making larger quantities and holding down carrying costs by frequent runs. The compromise quantitity is known as the Economic Order Quantity (EOQ). Japanese manufacturers have made efforts to reduce the set up time while in the mean time cutting the purchase order costs: and reducing the EOQ.

The basic idea of Just-in-Time (JIT) is simple: produce and deliver goods just in time to be sold, subassemblies just in time to be assembled into finished goods, fabricated parts just in time to go into subassemblies and purchased materials just in time to be transformed into fabricated parts. However when implemented, JIT is much more than inventory control: large lot size inventories obscure problems, when the lot size inventory is cut the causes of error are exposed.

Kanban is the name for a specific Japanese inventory replenishment system developed by Toyota. Literally translated, Kan ban means "visible record" "or visible plate" and it is taken to mean "plate". Most companies use a system employing order card which accompany work in progress; they do not constitute a Kanban system because they are employed as a push system of parts ordering and parts control. The Toyota Kanban system is a pull system; it provides parts when they are needed and therefore without excess inventory. Kanban will work well only in the context of a just in time system in general.

This system was designed at a time when all Toyota manufacturing system was done within a 50 kilometer radius. In the past years the company has opened plants in the United States. Despite of this JIT has been maintained and adapted: when ordering errors are made parts have to be flown from Japan; US suppliers make delivery to set-up depots where Toyota makes daily collections. This adaptation has forced the company to start Kan Ban plus alpha effect: high volume data communications links have been installed enabling the head office to monitor overall production. The objective is to turn JIT in real time: tomorrow's stocks will then be based on tomorrow's sales.

Extracted from Schonberger: Japanese manufacturing techniques, nine hidden lessons on simplicity, London Free Press 1982, and "Toyota Motor: Delivering tomorrow orders made today", Financial Times, September 10, 1990.

goods inventory. higher capital utilization through a higher degree of machines as well as overall plant utilization; faster product development, higher and more even quality of product.

Flexible automation has now become the best practice rule in engineering industries. The social impact of its diffusion concerns employment, work intensification, work organization and job contents.

1.3.1 Labour saving

Numerical controlled machines tools are labour saving. In the United Kingdom a conservative estimate in 1971[21] assumed that one NC machine could replace two manually operated machine tools, this ratio has increased significantly:

in 1976: 1 NC was equivalent to 2.5 non NC
in 1981 1 NC was equivalent to 3 non NC
in 1986: 1 NC was equivalent to 3.5 non NC

A CNC machining centre plus robot handling and tool management would require only one or two operators whereas the traditional arrangements replaced by this flexible manufacturing system, would have required ten or more direct operators.

On the basis of concrete examples surveyed in Sweden and the Federal Republic of Germany, the reduction in labour cost per unit of output has been estimated at one to two thirds depending of the type of application and the number of shifts.

To assess the impact on employment one has to take into consideration

- the direct effects: employment lost and employment generated in maintenance services (inside or outside the enterprise)
- the indirect effects: through the gains obtained because of the competitiveness acquired or the employment which could have been lost because of the lack of competitiveness caused by the non adoption of the new technologies

At a macroeconomic level, country case studies have not always shown any correlation between the unemployment rates and the use of flexible automation techniques. A European study found

(21) Metalworking Production, Sixth survey of the United Kingdom.

that job losses due to the introduction of CNC equipment represented less than 1 per cent of total job losses annually in the sector. Investment in electronic-based equipment has not led to significant job displacement, since against this reduction, there is the increasing requirement for indirect support in areas such as maintenance, production planning and computer programming.[22] "*It appears that on the whole job displacement and redeployment of workers in the course of innovation and rationalisation appear to balance each other and where technological change goes along with economic growth (..) it even tends to induce positive employment effects through the revitalisation of the economy.*"[23]

This labor saving impact is a particularly worrisome characteristic for developing countries. There does not exist any comprehensive study on developing countries and the level of introduction of NC is too low so that its employment impact is too limited.

1.3.2 Work intensification

The introduction of NC machine tools has an impact on work intensification. According to a recent study[24] the time effectively spent on the production process was on average 30% of the total production time when using conventional machine tools. A closer analysis of the total working cycle times showed that on average only 5 per cent of such time was effectively used to remove material; for the other 95 per cent, the piece occupied labour and machine, but had to wait to be worked because of placement, measurement, unloading, displacement, tool change, etc. In Sweden,[25] in 1981, about 20 per cent of the time spent by blue-collar workers in the engineering industry was spent on operating machine tools and a further 10 per cent was expended on

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(22) John Bessant: Microelectronics and change at work, International Labour Office, Geneva, 1989.
(23) K. H. Ebel: Computer integrated manufacturing, the social dimension, International Labour Office, Geneva 1990.
(24) UCIMU The Italian industry of machine tool, automation and robotic-Analysis of the recent evolution, 1989.
(25) Jacobsonn Edquist, Flexible automation-the global diffusion of new technology in the engineering industry, Basil Blackwell, London 1988.

tasks intimately connected with machining (e.g. setting, repair and maintenance).

The introduction of NC machine toolscan improved machine utilization, however one should not overrate the possible achievements. While the effective rate of utilization of conventional machine tools has been estimated at 6 per cent of its potential in French small and medium scale engineering firms,[26] it has been found that in most cases NCMT were utilized at 15 to 25 per cent of their potential.

1.3.3 Work organisation[27]

The changes in work organization introduced by numerical control machine tool has to be considered in historical perspective: The NC era came after four stages which were characterized by the introduction of new technologies and of new work organization (See Box 10 and Table 25).

With conventional machining technology, work organization was characterized by a relative separation between planning activities and workshop. The introduction of NC tends to reduce the relative autonomy of the workshop since the programmer and the operator have to coordinate their activities: the operator may find mistakes in the programmer's programme and his feedback

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(26) The machine is usually not working 94 per cent of the time: 6 per cent due to technical factors, 10 per cent due to mismanagement, 44 per cent due to the fact that the machine is used on a one shift basis instead of 3 shifts, and 34 per cent are due to stoppages during week ends and holidays in CETIM: Ameliorer la productivite des centres d'usinage et de tournage, December 1988.

(27) This part draws from several works carried out for the Ministry of Research in France and FAST programme in Europe. The main findings from these works were published. See W. Cavestro: Automation, Work Organization and Skills: the case of Numerical Control in Automatica Vol.22, Number 6, pp 739-746 and Automation, New Man-Machine systems and skills in International Journal of Robotics and Automation, Vol 3 Number 1 1988. See also John Bessant: Microelectronics and change of work, International Labour Office, 1989.

Box 10: Five hundred years of technological and organizational changes

Founded in 1492 Beretta has been engaged in the manufacture of firearms and production has gone through six main epochs:

In the English system process improvements tended to be made independently of product constraints: drawings replaced models and one needed accurate measuring instruments.

The American system was based on interchangeability of parts because of the need for a large number of identical components. The organization of work changed with a clear separation between those who built, maintained, set up and improved the machines and those who turned out parts by the hundred.

Taylor introduced the concept of scientific management. Job analysis implied narrowing of the functions and a trimming off of all variant non repetitive tasks. Work was standardized and the control of work was in the hands of management.

The introduction of statistical process control (SPC) altered the organization of work. It required only that process behavior for a sample of parts be recorded on charts at specifics intervals of time. In the dynamic view introduced by SPC, work was defined in terms of identifying problems and diagnosing and solving for them; supervision consisted not in monitoring effort but in facilitating changes.

With NC the scope of activity has greatly expanded and the number of possible products increased due to the versatility of the equipment. The nature of work changes, an NC operator works not on physical objects but with information. The work ethos changes from monitoring machines to controlling them and system engineering replaced quality as the dominant engineering ethos.

In the era of computer integrated manufacturing, the worker is likely to be completely separated from the physical elements and work may become an act of conception, of creating new products and processes.

Source: Jaikumar: From Filling and fitting to flexible manufacturing, a study in the evolution of process control, Division of Research, Harvard Business School, February 1988.

Table 25: Six stages of work organization

	English System	American System	Taylor Scientific Management	Dynamic World	N.C. era	Computer Integrated Manufacturing
	1800-1850	1850-1900	1900-40	in the 50's		
Number of machines	3	30	150	150	50	30
Minimum scale (number of persons)	40	150	300	300	100	30
Staff Line ratio	0:40	20:130	0:240	100:200	50:50	20:10
Rework as a fraction of work	.80	.50	.25	.08	.02	.01
Number of products	infinite	3	10	15	100	infinite
Engineering ethos	Mechanical	Manufacturing	Industrial	Quality	Systems	Knowledge
Organizational changes	Break up of Guilds	Staff/line separation	Functional Spezialisation	Problem Solving Teams	Cellular Control	Product Process Program

From Jaikumar: From Filling and fitting to flexible manufacturing
Harvard Business School, Working Paper 1988.

will be then essential to ensure improved future programme quality; using his expertise, the operator may possibly have different ideas as to the choice of tools.

The machine operator of a conventional machine used to set up the machine with the help of a technical diagram containing instructions supplied by the work preparation department. He determined the rotary speed of the component, the choice of the tool and the subsequent design of the product. All these tasks require a great deal of expertise. In the case of NC, programming becomes a function which is distinct of production and which, therefore, can be carried out either within the methods department, thus reinforcing a taylorist organization of work, or in the workshop. (Box 11 and Figure 21).

International comparisons demonstrate a great diversity of situations. Thus in the Federal Republic of Germany the programming of NC machine tools tends to move towards, if not carried out in, the workshop without any substantial skills differentials between the workers involved. The distinction between programmer and operator is much less marked than in France or in the United Kingdom except in the case of the machine tool industry, where there exists a strong tradition of artisan labour, planning and work execution are carried over in the workshop.

Programming in the workshop in the Federal Republic of Germany resemble Japanese work organization, the functions of work programming/planning and work execution are highly interdependent and coexist with highly mobile operators and programmers, the same individual will work both in the methods department and near the machine tool. In German machine tool industries, automation was at first threatening since programming NC machines off the shop floor disrupted established workplace relations; but as the NC machines proved to be compatible with the high skill level of the workers and the de-facto decentralization of production these industries accepted such automation. "*Companies are increasingly seeing the merits of stressing craft skills as a viable option when implementing the new technology... There is a striking kinship between the increasing use of CNC and the renewed interest by companies in training and employing skilled workers.*"(28) Adjustments which were carried out manually are now analyzed by the computer with

(28) G. Hartmann quoted in Piore and Sabel (1983).

Box 11: Evolution in work organisation: the case of sheet metal manufacturing

In traditionally organized firms, the process of production begins with the cutting of the sheet metal on guillotine shears. Then the forms are traced on the metal followed by punching, touch up, folding or forming and assembly operations.

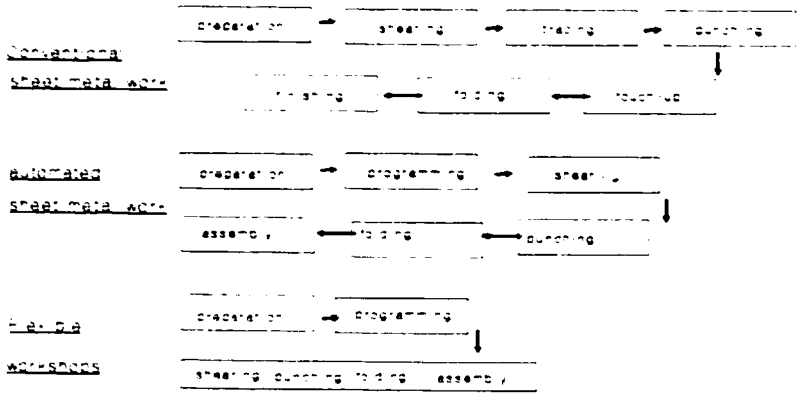
With the introduction of NC machine tools the overall process is modified through the elimination of certain stages of production.

Numerical control eliminates in particular all tracing work: this skilled activity called for knowledge of trigonometry and engineering drawing. It consisted in reproducing on the sheet metal, in real size, the drawing of the part in order to provide a model for machine operators. Similarly the touch up operations which took place after the punching in order to separate the parts and straighten out the sheet metal, disappear as a result of the possibility of cutting out the parts on punching and nibbling machine.

With the introduction of flexible cells, shearing, punching and folding operations are grouped together in a continuous flow. (see Figure 21)

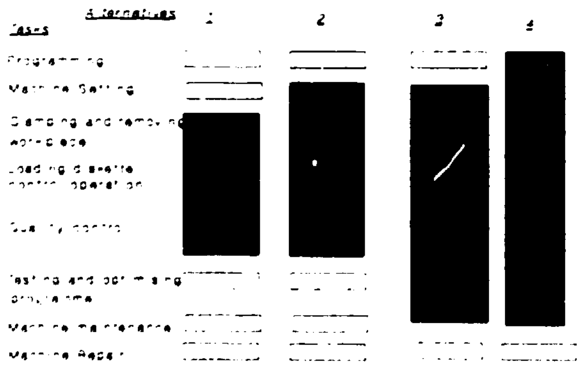
Adapted from W. Cavestro: "Automation, work organization and skills" in International Journal of Robotics and Automation, Volume 3 Number 1, 1988.

Figure 21 Reorganization of the workshop



Adapted from W Cavestro, International Journal of Robotics & Automation Volume 3 Number 1 1988

Figure 22 Alternative jobs for CNC machine operators



much greater accuracy. However a degree of human control is still necessary. For example[29] raw materials such as cast iron the quality of which varies enormously: it could be necessary to make minor adjustments to computer programmes in order to achieve good results.

Thus it appears that work organization and technological alternatives are largely interdependent: the programming function takes root in pre-existing organization of work and transforms it in a more or less contradictory manner. There is considerable range of jobs design for CNC machines, from simple to more complex alternatives as shown in the example of Figure 22.

The existence of such choices of organizations opens up possibilities for developing countries since it suggests that flexible automation can adapt to local circumstances and the constraints of skills availability.

1.5.4 Skilling or deskilling

The impact on skills of electronics based technologies is still a subject of debate. Some argue that microelectronics is a fundamentally de-skilling technology since it continues the long established trend of mechanization by substituting for intellectual activity, judgement and experience. Opponents to the deskilling thesis stress on the contrary the positive impact of automation on these workers skills. However one should stress that these new technologies will not offer employment to low skill workers.

Numerical control changes the nature of skills in two ways. Firstly the know-how of the skilled worker is partially "memorized" upstream from production. Secondly, the functions of execution and command tend to be transferred to the machine itself. However during this process workers' skills can be said to be redefined as new opportunities emerge.

The operator of a NC machine tends to be in charge of tool management, a highly skilled function which consist of defining the appropriate tools with respect to the program, the required

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(29) A.J van Duren and M.van Manen: Flexible production automation: a description and definition, Technovation, 9 (1989), p 389-399.

quality of the machining and the wear and tear of the cutting tools. The programmer does not give all the characteristics of the cutting tools and the operator has scope for modifying tooling choices with his prior knowledge of the reaction of the tools on given materials.

During the operation, the role of the operator is not restricted to passive supervision. He frequently intervenes on machining conditions in collaboration with the machine setter or the programmer. The optimization of a program tends rapidly to increase the operator control over the machining conditions particularly in the case of CNC machining centers. Numerical control does not destrcy worker know-how but rather re-employs it. The specific engineering know how must be accompanied by proficiency in understanding the interrelations between languages, machining and incident indicators (noises, sparks, types of metal shavings). The codification of the machine does not necessarily imply that the operator can no longer intervene in workshop processes. The human operation is caught in an interactive relationship, in which the worker know how is transferred to programmes, but in return the operator progressively assimilates the codes and languages which command the operations of the machines. The operator has to select among a greater number of informations which are either digital or informal.

Transformation of work qualification appear also outside the workshop: electronics qualification play an increasing role and maintenance technicians are required to have highly diversified qualifications. Computer languages used by the programmer or operator to write control programmes for machines are constantly changing and new languages offer new possibilities. Software maintenance becomes a priority; however this task can be achieved by either the programmer or the operator in charge of the machine.

In summary, advanced production technologies are not to be considered as an alternative to skilled workers. It is the capacity to manage the continuous evolution of the production system and not merely the ability to operate an automated factory that is the competitive meaning of postindustrial manufacturing.[30]

1.4 From stand alone to computer integrated manufacture

It is important to stress that the diffusion of flexible automation equipment is taking place within a context of growing integration within the enterprise which is bringing together what were once discrete activities.[31]

This evolution started within each one of the different spheres of production through intra-activity automation in a stand-alone fashion. In the 1950s and the 1960s, with the advent of numerical control, it became possible to incorporate the knowledge and experience of skilled operators into a controlling programme held on paper tape. In the 1970s, the development concerned the integration of the programming itself into CNC shop floor programming systems.

A similar trend towards integration can be found in the design sphere where the various stages of drawing preparations, converting ideas and modifications into a full set of engineering drawings are now contained within a computer-aided design (CAD) system.

The second step of automation concerns the integration of individual activities in intra-sphere automation. In the production sphere, the flexible manufacturing system links several CNC tools and handling systems under direct numerical control supervised by a host computer.

Because microelectronics can be used in all information-based activities, the technology can be introduced

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(30) S. Cohen, J. Zysman, "Diverging trajectories: Manufacturing innovations and American Industrial competitiveness" in Politics and productivity, page 45.

(31) See Kaplinsky, Automation the technology and society, Longman, London 1984 and Bessant Integrated automation in batch manufacturing, OECD Directorate for Science, Technology and Industry, 1986, and John Bessant Integrated Manufacturing Technology trend series, number 8 Unido 1988.

into the different spheres[32] of a manufacturing firm from production management, administration, design and process specifications, and raw material processing, to packaging, testing and inspection of final products and manufacturing processes. The pattern of integration within each sphere of activity, is now followed by a trend of integration between spheres, CAD/CAM systems linking design and production and FMS systems linking coordination and production. In this third level of inter-sphere automation the different spheres will eventually be integrated and coordinated in a full computer integrated manufacturing system.

Due to this trend towards integration, software costs represent an increasing share in capital investment. Data gathered by IAASA[33] shows that one third of the cost of a stand alone numerically controlled machine tool is attributable to software. In the case of flexible manufacturing systems, half of the cost are attributable to NCMT - of which software account for one third- and systems control, communication and interfacing software adds another twenty to thirty percent. Software cost is said to account for 50 per cent of one recent Japanese automated factory. (Table 26)

2 Automation in stand-alone equipment

Automation technologies have been introduced on the basis of stand-alone equipment. Even though numerically controlled machine tools have been a success, they can be considered as a substitution innovation, which offers a more efficient way of doing the same thing. (Box 12)

Due to the retarding effect of the recession in the early 1980s, the diffusion of automation has occurred more slowly and more unevenly than was expected; the investment climate was not conducive to firms undertaking new investments in new technology. Since 1982, real capital spending has grown more than twice as fast as GDP in OECD countries and this increase has led

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(32) K. Hoffman: Technological advance and organizational innovation in the engineering industries. Industry and Energy Department working paper. Number 4, March 1989.

(33) R. U. Ayres: Technology forecast for CIM in Manufacturing Review vol 2, Number 1, March 1989.

Table 26: Software in total investment

Sofware fraction of total investment	Span of Computer control	Added to prior level
2%	Stand Alone machine	Instructions for machine control
3%	Machining Center	Instructions for changing tools
4%	Machining Cell	Multiple machine control
6%	FMS (1)	Scheduling
10%	FMS (2)	Loading/Unloading Storage
15%	FMS (3)	Inspection Sorting
20%	Automated Production line	Assembly, palletizing, Kitting
40%	Automated Factory (1)	Computerization of functional modules viz MIS, MRP,CAD, CAPP,CAM
50%	Automated Factory (2)	Linkage with MIS, MRP, Order Processing, Scheduling, Cost Analysis
70%	Automated Factory (3)	Linkage of CAD,CAE,CAPP & CAM

Adapted from R.U. Ayres: Technology forecast for CIM in Manufacturing Review March 1989

Box 12: Softening "Hard" Automation

NC machines which are characterized as "soft," or programmable automation, have five characteristics.

(1) Specificity of procedures. Because the computer is static and functionally blind, the procedures must be written as if to guide a blind person restricted to a small set of activities in a finite space. The specificity of the procedure, together with removal of the person from the immediate environment of work, renders the activity more abstract and scientific.

(2) Adaptability to change. Programmes can be changed easily. Quality is no longer front-end loaded, but subject to constant improvement that can be monitored, and modified at the work station. There are frequent and incremental changes in procedures, which do not require centrally allocated resources. Work at a station no longer involves just monitoring performance, but improving it as well.

(3) Versatility of operations. Operations at a station are only restricted by the configuration of the part being machined, i.e., whether it is prismatic or rotational. Within each class, the machines can perform almost any operation, restricted only by the availability of tools and the tolerances they are capable of maintaining. Thus the scope of activities at an NC work station is expanded to include the introduction of new parts and processes.

(4) Reproducibility. Once a program is written, the machine controller is capable of executing the program flawlessly forevermore: the better able a program is to deal with contingencies , the less need the machine will have for a skilled operator. An operator writing a procedure is, in effect, "cloning" him or herself. This creates a managerial imperative to constantly introduce new products and processes in order to keep skilled people in the organization occupied.

(5) Transportability. A reproducible program's use is not restricted to the machine on which it was developed. It can be used on any identically configured machine, and it can be copied at no cost. Thus, once a program is written, parts can be subcontracted to any small job shop with equivalent equipment without a great deal of concern for quality.

From Jaikumar: From filling and fitting, Harvard 1988.

to a rebound in machine tool sales which has been accompanied by a larger increase in NC machine tool sales. Japan has been a forerunner and the ratio of NCMT in machine tool shipments, measured in value, increased from 29 per cent in 1976 to 60 per cent in 1983 and 70 per cent in 1988 in the case of metal cutting machine tools(34) and 19 per cent in the case of metal forming machine tools.(35)

One of the main factors contributing to the diffusion of NC has been the decline in relative price compared to conventional machine tool. This is illustrated in the case of lathes in Japan (Figure 23) where the price ratio between CNC lathe and conventional lathes dropped from 8.3 in 1974 to 2.9 in 1988. It should be noted that the rapid diffusion of NC in Japan occurred after the introduction of the microprocessor which had an accelerating effect on the decline in price of the control unit (Figure 24).

The combined production figures from the United States of America, the United Kingdom, Germandy (F R G), Italy and Japan show that the share of NC machine tools in total machine tool shipments has increased from 21 per cent in 1976, to 41 per cent in 1982 and 57 per cent in 1988. As can be seen (Table 27) the ratio of NCMT in machine tool consumption (production plus imports less exports) is more homogeneous than the similar ratio concerning production .

After a review of the main evolution in the design of machine tools in the next section, an analysis on a sectoral basis of the diffusion of NCMT in the engineering industries of the industrialized countries will be presented.

2.1 Evolution in the design of stand-alone machine tools

The principal innovation has been the introduction of NC, however in the conventional field of machine tools there has been a vast number of incremental advances. The mechanics of machine

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(34) The demand for replacement of NC metalcutting machine tools represent 779 billions of Yen (of which 263 billions for NC lathes), that is 78 per cent of acquisitions in 1988, Asia Wall Street Journal, June 22 1989.

(35) According to Japan Forming Machinery Association statistics which did not document any NC production before 1988.

Figure 23 Diffusion of NC lathes (Japan)

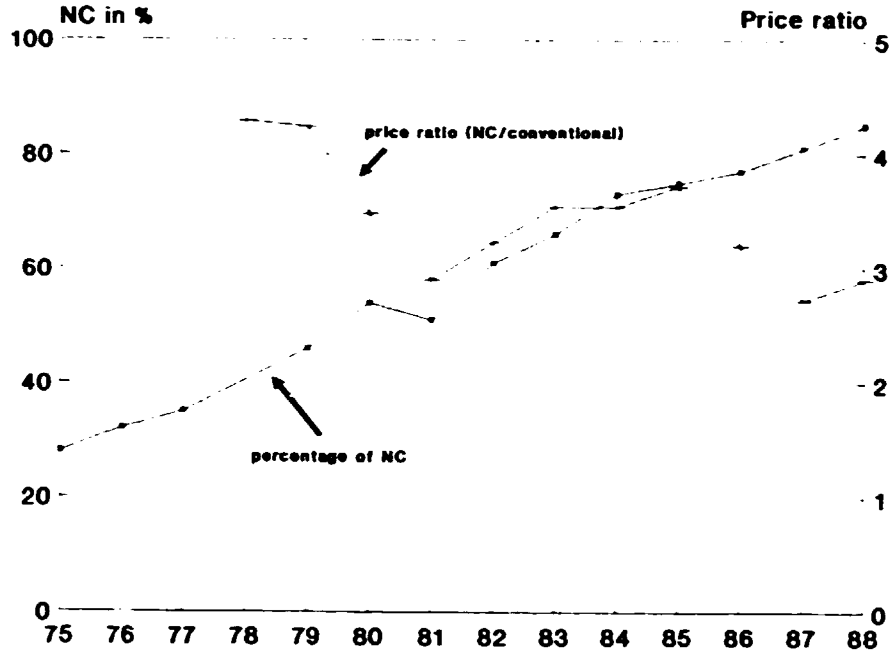
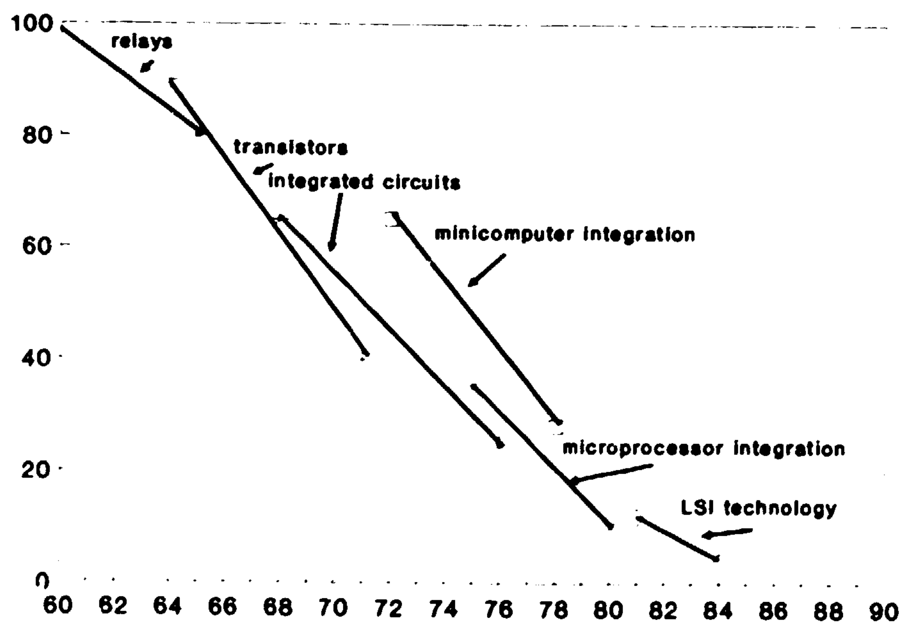


Figure 24 Impact of innovation in electronics on Numerical Control price



Adapted from Hans Kief

Table 27: NC machine tool in percentage of production and consumption

(measured in value of metal cutting machine tool in selected countries in 1988)

Production	France	FRG	USA	UK	Italy	Spain	Japan	Together
Drilling	.0%	32.2%	.0%	.0%	.0%	5.6%	69.0%	37.8%
Milling	89.2%	80.8%	47.2%	.0%	87.6%	60.5%	62.0%	71.4%
Shaping, slotting, sawing	.0%	57.3%	.0%	.0%	.0%	.0%	21.3%	25.3%
Lathes	91.8%	74.6%	84.0%	36.7%	70.4%	52.9%	89.5%	80.3%
Grinding and Polishing	6.7%	45.5%	.0%	.0%	.0%	29.5%	26.0%	26.0%
Boring		65.2%	.0%	89.3%	.0%	72.7%	50.0%	43.6%
EDM and ECM	33.3%	58.5%	.0%	.0%			95.3%	82.6%
Gear Cutting	.0%	63.5%	.0%	.0%	.0%	.0%	.0%	33.3%
machining centres and transfer	92.7%	79.4%	54.9%	74.3%	49.8%	59.8%	100.0%	79.5%
Total Metal cutting	77.8%	63.0%	35.5%	62.6%	38.0%	48.6%	70.7%	60.5%
Total NC US$ millions	470	2972	584	478	757	253	4752	10266
Consumption								
Drilling	42.0%	27.0%	17.0%	100.0%	.0%	25.0%	67.0%	39.0%
Milling	80.0%	78.0%	43.0%	26.0%	97.0%	61.0%	61.0%	68.0%
Shaping, slotting, sawing	.0%		.0%	.0%	.0%	.0%		40.0%
Lathes	84.0%	68.0%	91.0%	57.0%	77.0%	62.0%	85.0%	80.0%
Grinding and Polishing	52.0%	53.0%	1.0%	.0%	7.0%	15.0%	21.0%	24.0%
Boring	94.0%	54.0%		100.0%	.0%	100.0%	40.0%	
EDM and ECM	88.0%	57.0%	46.0%	.0%	.0%	.0%	87.0%	72.0%
Gear Cutting	7.0%	73.0%	.0%	69.0%	9.0%	50.0%	.0%	21.0%
Machining centres and transfer	92.0%	92.0%	67.0%	76.0%	59.0%	65.0%	100.0%	81.0%
Total Metal cutting	74.0%	64.0%	47.0%	68.0%	46.0%	49.0%	64.0%	59.0%
NC metal cutting	825	1950	1284	503	790	248	2918	8518

tools have changed little in concept but greatly in design and control.[36]

2.1.1 Structure

The machine-tool frame or bed is its largest element to which all others are attached. The frame must provide structural strength and stability and be able to withstand vibrations. Machine tool structures are principally made from cast iron which tends to be the preferred material because it can be easily cast and machined to provide good resistance. The search for cheaper alternatives has spurred research in the use of steel welded fabrications of concrete filled steel shells. Concrete compositions utilizing epoxy, metracilate or polyester resins are being introduced as granite materials.

2.1.2 Guideways and bearing surfaces

New design concepts are now being tried to ensure the longevity of machine accuracy, to reduce periodic maintenance and to provide for easily replaceable guideway elements that do not require costly and time-consuming scraping. Recent innovations in guideway technology have resulted in the development of glued-on and fixed-on drives whose cost is much less than even the conventional precision milled or hand-scraped guideways.

2.1.3 Spindle systems

Technology for bearings has enabled higher spindle speeds to be achieved; speeds up to 6000 rpm are now achieved while the development of new ceramics bearings has enabled speeds to rise: machines capable of 40 000 rpm have been displayed and some believe that the introduction of machines capable of 100000 rpm spindle speeds is not far off.

The thermal energy dissipated in the machine spindle-head during operations leads to considerable thermal dilatation which causes spindle drift and spindle droop. Thermal problems can be overcome by controlling and stabilizing the operating temperature

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(36) This part summarizes a report from S.M. Patil: Technological Trends in machine tools and their implications for developing countries, Technology Trend Series, No 10, IPCT/101, UNIDO 21, December 1989. It also draws from the Study on EC machine-tool industry.

of the spindle head and by keeping it cool through refrigeration. Drift and droop can be compensated through the use of hydrostatic bearing systems and with pressure feedback in respect of a built in reference.

2.1.4 Feed drives

The drive of a machine tool is provided by a combination of electric motors and a gear train. Electronics innovations have led to the development of a new breed of feed drives: electrohydraulic are being phased out and electronic servo drives dominate the field. In these high performance drives DC permanent magnet systems are the most commonly used.

2.1.5 Mechanical drive elements

Along with the direct drive DC servos and torque motors, the most commonly used mechanical drive elements are recirculating anti- friction screws and nuts. However, the hydrostatically lubrificated nuts and lead-screws systems are recently found and increasingly used applications in the machine tool field because of lower rumble, higher stiffness and low friction.

2.1.6 Accuracy of design

The design of modern machine tools is aimed towards high accuracy of machine components. In this context an integrated approach should be adopted for the design of the machine and controls. It should satisfy a dual purpose: the machine has to be able to machine a component and to take over the added function of inspecting the machined job which requires the incorporation of a number of measuring devices and system on the machine tool. The most commonly used servo-positioning aids are the indirect types of transducer, however the direct types such as inductive scales and moire fringe gratings are finding increased use because of their higher precision.

2.1.7 Ergonomics, noise and safety

Operator-machine relationship is particularly important on manually operated machines and new concepts are emerging to design a lathe which can be operated by a seated person. To cope with visual communication through symbols, there is a demand for an international recognized code of symbols.

Recent recommendations on acceptable shop noise levels and mandatory safety regulations point to an increasing obligation of the machine tool builder to meet even more stringent regulations.

While the regulations are more stringent for metal forming equipment, metal cutting tools are also subjected to mandatory safety regulations concerning guards and seals to protect the operacor from chips, coolants and other hazards.

2.1.8 Materials for tools

The cutting tool is directly related to machine productivity. A number of new materials have been introduced or are being developed. One of the major breakthroughs has been the advent of cemented carbide for metalcutting. Many non-tungsten cutting tool materials have been used, the most promising being titanium carbide and titanium nitride tool material.

2.2 Diffusion of numerical control machine tools

The introduction of micro-computer based control units in the seventies allowed automatic tool changing which has been one of the most significant benefits of NC technology in stand-alone equipment. Metal-cutting machine tools are the most widely used machine tools, accounting for 75 per cent of installed units, and it is in the case of these machines that the diffusion of numerical control has been most important.

To assess the diffusion of NC machines, inferences will be made from the evolution in shipments and consumption of machine tools as shown in Table 27 which gives detailed production and consumption data (in value) for the main producer countries(37) in 1988; and from the diffusion of NC in the apparent consumption of machine tools in units shown in Table 28. Whenever possible, the analysis will be based on the recent inventories carried out in the United Kingdom, the United States of America and Japan.

While NC machine tools represent around 50 to 70 per cent of the value of the machine tools purchased in most industrialized countries, they represent on average from 20 to 40 per cent of the consumption measured in units terms and from 5 to 15 per cent of the number of machine-tools installed within the engineering industries. Measures in units underestimate the role

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(37) Excluding Switzerland and Sweden which do not publish a desegregated structure of their NC machine tool production.

of NC machine tools in the engineering industries. When a conventional lathe is being replaced by a NC turning center, it cannot be considered as a one to one substitution: the ratio of utilization of the NC turning center will be three to five times higher. In the case of France, where NC machine tools represent 12.7 per cent of the installed capacity, it has been estimated that around 50 per cent of the machining operations are now realized on NCMT.[38]

The emphasis given to NCMT should not relegate the importance of conventional machines. The market for conventional machine tools remains large with demand coming from small and medium enterprises, maintenance shops, tool rooms and general engineering backup services.[39] (See Box 13).

2.2.1 Lathes

Numerical Control lathes are the most widely used NC machine tools

Shipment: According to Table 27, 89.5 per cent of lathes produced in Japan were NC (74 per cent in units). In Germany (F R G) NC lathes represented 74.6 per cent of lathe production.

The production of NC lathes is highly concentrated in Japan (around half of world production) other main producers are Germany (F R G) and Italy (Table 29).

Consumption: In value terms, NC lathes represent almost 90 per cent of the apparent consumption of lathes, while in units (Table 28) the ratio is around 30 to 70 per cent in the main industrialized countries.

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(38) P. Fremeaux, R. Touboul: Machine outil 90, les enjeux, Bureau d'Information et de Previsions economiques, Paris 1990.

(39) Having put too much emphasis on NC machines, DECKEL SA, the second largest German machine tool manufacturer, has lost many of her traditional customers, mid sized companies, which found the new technologies too complicated, and this explains some of her recent difficulties ("Decked by blunders", International Management June 1990).

Box 13: Future of conventional lathe

Over a half of the respondents to a survey on turning lathes among British metalworking firms indicate that the parallel central lathe will stay as it is, whilst only one in four said the same about capstan, turret and automatic lathes.

Types of turning machine installed since January 1987:

NC/CNC lathes (turning only)	32
Non-NC parallel (centre) lathes	14
NC/CNC lathes driven tooling	13
Non-NC turret, capstan and automatic lathes	9
Other Non-NC turning machines	7
None of these	28
Not stated	21

Source: Metalworking Production, March 1989.

Table 28: <u>NC diffusion in apparent consumption</u>

(measured in units in 1988)

	Germany	United States	United Kingdom	Italy	Japan
NC drilling	258	273	33	1259	
NC milling	3623	1101	616	2067	
NC Lathes	3060	6144	879	1730	12897
NC Grinding and Polishing	2454	75	401	58	798
NC Boring	505	223	1007	93	
NC EDM and ECM	733	92	0	0	3464
NC Gear Cutting	485	65	42		
NC Machining centres and transfer lines	1116	3913	1170	2151	7177
NC metal cutting	17650	11878	893	4297	
NC drilling	0%	3%	1%	0%	3%
NC milling	42%	8%		46%	35%
NC Lathes	29%	53%		29%	70%
NC Grinding and Polishing	2%	0%	1%	4%	1%
NC Boring	30%	23%	100%		12%
NC EDM and ECM	100%	4%			100%
NC Gear Cutting	100%	0%	3%	25%	
NC Machining centres and transfer lines	100%	90%	100%	100%	100%
NC metal cutting	5%	1%	2%	5%	

<u>Source</u>: Computed from CECIMO statistics.

Table 29: Production of NC machine tools in selected industrialized countries in 1988
(US$ millions)

	France	FRG	USA	UK	Italy	Spain	Japan	Total
NC drilling	0	29	0	0	0	1	118	148
NC milling	74	550	84	0	183	89	230	1210
NC Shaping, slotting, sawing	0	102	0	0	0	0	17	119
NC Lathes	89	788	226	47	252	54	1550	3006
NC Grinding and Polishing	1	376	0	0	0	13	217	607
NC Boring	0	101	0	50	0	8	74	233
NC EDM and ECM	2	79	0	0	0	0	549	630
NC Gear Cutting	0	146	0	0	0	0	0	146
NC Machining centres,transfer lines	177	759	274	176	322	58	1578	3344
NC metal cutting	470	2972	584	478	757	253	4752	10266
					Percentage			
NC drilling	.0%	19.6%	.0%	.0%	.0%	.7%	79.7%	100.0%
NC milling	6.1%	45.5%	6.9%	.0%	15.1%	7.4%	19.0%	100.0%
NC Shaping, slotting, sawing	.0%	85.7%	.0%	.0%	.0%	.0%	14.3%	100.0%
NC Lathes	3.0%	26.2%	7.5%	1.6%	8.4%	1.8%	51.6%	100.0%
NC Grinding and Polishing	.2%	61.9%	.0%	.0%	.0%	2.1%	35.7%	100.0%
NC Boring	.0%	43.3%	.0%	21.5%	.0%	3.4%	31.8%	100.0%
NC EDM and ECM	.3%	12.5%	.0%	.0%	.0%	.0%	87.1%	100.0%
NC Gear Cutting	.0%	100.0%	.0%	.0%	.0%	.0%	.0%	100.0%
NC Machining centres,transfer lines	5.3%	22.7%	8.2%	5.3%	^.6%	1.7%	47.2%	100.0%
NC metal cutting	4.6%	28.9%	5.7%	4.7%	7.4%	2.5%	46.3%	100.0%

Computed from CECIMO statistics.

Inventory: As can be seen from Table 30, in the United Kingdom, while the number of non-NC turning machines declined by 5% between 1982 and 1987, the number of NC machines rose by 99% in the same period; NC machines represented 10% of non NC machines in 1987 as against 4% in 1982. In the United States a similar evolution has occurred.

The present technological trend is to have a single combination turret which can hold tools for both internal and external diameter turning. More sophistication is now built-in in order to machine a part in a single set-up; simple two axis lathes have given way to four-axis lathes.

The design of turning centres has moved the ordinary lathe into new areas of capability; they are now able to completely manufacture parts in a single operation in much the same way as machining centres produce prismatic components: "*Turning centers refer to a machine tool basically designed to machine cylindrical features on a rotating workpiece, plus additional powered tooling able to carry out secondary machining with the work piece stationary, -with or without automated tool changing and/or workpiece load/unload*". The machines are capable of simultaneous machining operations under multi-axis CNC operation using standard tools in separate tool turrets. This ability to produce completely finished parts depends on being able to bring a variety of tools to machine the workpiece in one set up; turning centres are able to mill, drill, tap and bore as well as turn; they can also perform several similar operations simultaneously.

Laser turning experiments are also underway, and three dimensional lasers for cutting and welding are seen by the automotive industry as a means to introduce body panel options at a later stage of the car assembly process.[40]

2.2.2 Boring, drilling and milling

Boring and drilling can be performed either by the use of lathes or by drilling, boring and occasionally milling machines. Machines capable of performing a variety of operations have been developed over the years, with CNC milling, boring and drilling

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(40) Metalworking Production: Machinery 75th Anniversary.

Table 30: Diffusion of Numerical Control in Turning

United Kingdom inventory

in units	1982	1987	87/82
NC turning	7883	15723	99.5%
NC/non-NC in percent	4.5%	10.7%	
Non-NC turning	174374	147329	-15.5%
turret, capstan and automatic	81117	55996	-31.0%
parallel lathes	72292	55185	-23.7%
year of acquisition of Non NC			
0 5 years	22.0%	23.0%	
> 20 years	33.0%	29.0%	

US inventory

	1983	1988	88/83
NC turning	33352	74077	122.1%
NC/non-NC in percent	9.1%	18.3%	
Non-NC turning	332327	330357	-.6%
year of acquisition of Non-NC			
0 4 years	11.0%	8.6%	
> 20 years	40.0%	38.6%	

Sources: Sixth survey of machine tools
Metalworking production
American Machinist, November 1983 and November 1988

progressively replacing conventional machines.

Shipments: As can be seen from Table 27, NC drilling machines represented on average 37.8 per cent of total drilling machine tools in 1988 (69 per cent in Japan); in the case of milling machines the average ratio was 71.4 per cent and for boring machines it was 43.6 per cent.

Largest producers are Germany (F R G) followed by Japan.

Consumption: NC machines represent on average 68 per cent of the apparent consumption of milling machines, 39 per cent for drilling. In units terms (Table 28), the percentages are much lower (35 per cent for milling in Japan, between 10 and 30 per cent for boring).

Inventories: In the United Kingdom, NC milling machines represented 21% of acquisition in new milling machines between 1981 and 1986, against 8 per cent between 1977 and 1981 while for NC boring machines the increase was from 15 to 21 per cent and for NC drilling machines from 2 to 6%.

NC milling, drilling and boring machines are themselves substituted by machining centres which perform a combination of operations.

The automatic toolchanger has historically distinguished the machining centre from other machine tools. They come in either horizontal or vertical spindle configurations, the choice between the two depending upon the centre of gravity and the shape of expected workpieces. Horizontals are used for heavy workpieces while verticals are preferred when three-axis work is done on a single face (e.g. in mold or die work).

Shipments: While in 1976 machining centres accounted for only 38 per cent of the production of machines performing the milling function, the share rose to 65 per cent in 1986 in the major OECD machine tool producing countries. Available country data show that share was 81 per cent in Japan in 1988 and 39 per cent in Germany (F R G). The share of CNC milling machines stagnated while the share of conventional milling machines showed a continuous decline (7 per cent in Japan in 1988).

Table 31: Machining centres and milling
Trends in US inventories

	machining centre	share	NC milling		conventional milling	
1983	24003	*9.3%*	15929	*6.2%*	218479	*84.5%*
1988	52585	*17.4%*	28260	*9.4%*	220846	*73.2%*
increase	119.1%		77.4%		1.1%	

Source: Computed from the American Machinist

Inventories: In the United Kingdom, acquisition of machining centres increased very rapidly with three quarters of machining centres being acquired during 1982-86. Machining centres are second to turning machines in terms of stocks of NC machines.

2.2.3 Grinding

The diffusion of numerical control techniques grinding operations started in a significant way only in the 1980s; grinding had remained a manual process dependent on the expertise of the operator.

Cylindrical grinders were the first to benefit from CNC. NC has also been applied to surface grinders. Toolmakers have been reluctant to switch to numerical control, citing small batch sizes, non repeatability of orders and cost as main reasons; the producers had to develop their own control unit or buy a standard CNC and develop appropriate software from their own grinding expertise.

Most surface grinders in use are manual and unlikely to be replaced in the foreseeable future. Not everyone agrees in CNC being the only alternative: accuracy and quality depend equally on variables such as machine design and type of abrasive wheel.[41]

Shipments: The share of CNC grinding machines in major OECD machine tool producing countries was only 1 per cent in 1976; it rose to 11 per cent in 1984 and to 26 per cent in 1988 (Table 27). Major producer countries are the Federal Republic of Germany and Japan.

Inventory: NC grinding represented only 2 per cent of total grinding installed in 1987 in the United Kingdom; their share in new acquisition increased rapidly from 2 per cent in early 80 to 9 per cent in 1986.

The grinding machine is also evolving towards a grinding cell, which can easily be linked to others via automated guided vehicles. Some NC internal grinders have expanded their versatility by adding light duty turning functions.

2.2.4 Other metal cutting machine tools

Among other metal cutting machine tools, NC diffusion is rapidly increasing in the case of Electro Physical Machines and electro-discharge machines (EDM). This equipment lends itself to automation because all parameters can be monitored continuously.

EDM is also used with small and fragile complex components which, due to their minuteness, are in increasing demand in the electronics industry. More than 90 per cent of EDM produced in Japan are NC and 58 per cent in the Federal Republic of Germany. The inventory in the United Kingdom found "that one of the most meteoric growths (in Numerical Control) lies with the NC physico-chemical categories which are widely used by subcontractors within-house toolmaking facilities who are exploring the CAD/CAM route linked to NC-EDM and NC-milling.

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(41) Machinery and Production, March 1989.

2.2.5 Metal forming machine tools

Metal forming machine tools traditionally represent 25 per cent of world production of machine tools. Several indications suggest that these machines will represent a growing share of world demand, and will compete in some segments of activities with metal cutting machine tools. Their use allows reduction in machining sequences which are otherwise inevitable in metal cutting. Their success in this competition rests on three factors: the ease with which the manual content can be minimized, the degree to which they lend themselves to small batch production; and the reduction in tooling (dies and formers) costs which occurs with the increasing use of CAD/CAM and CNC.

The diffusion of NC techniques in metal forming machine tools has been somewhat slower than for those for metal cutting.

> Shipments: In Germany (F R G), NC machines represented 19 per cent of machine forming tools in 1988, 70 per cent in the case of shearing and punching machines, and 30 per cent in the case of pressing machines.
>
> Inventories: In the United Kingdom the proportion of NC metal forming machine tools in total machine forming machine tools grew from 1.2 per cent of installed capacity (in units) in 1981 to 2.4 per cent in 1986.

2.3 Diffusion of NCMT among industrial sectors

The analysis of the diffusion of NCMT among industrial sectors and of its evolution during the last decade offers valuable information concerning the trend of industrial automation in engineering industries. It may help to determine which sectors the use of NCMT is becoming by and large a standard, a result which will affect the rules of competitiveness.

2.3.1 Overall evolution

Inventory statistics measure the actual number of machines existing in manufacturing plants and they give an indication of the useful life of productive assets as well as the relative modernity of the engineering industries. Due to the longevity of machine tools. conventional machine tools represent the largest number of machine tools installed in the industrialized countries.

In Japan (Figure 25). the Ministry of Trade and Industry has conducted seven inventories since 1952.(42) NC machines appeared in surveys for the first time in 1967 and the number of NC metal cutting machine tools was 769. Their number rose very significantly from 1975 and their share in the total stock of machine tools increased from 3.6 per cent in 1981 to 10.7 per cent in 1987. In the last survey, figures for NC metal cutting tools (limited to those less than three years) rose to 33 per cent (compared to 12 per cent in the previous survey).

In the United Kingdom (Figure 26) the number of NC machine tools in use was 25800 in 1982 and went up to 52400 (excluding robots) in 1987 out of a total of 748000 installed machine tools within British industries. The ratio of NCMT in the total stock of machine tools increased from 0.2 per cent in 1970 to 7 per cent in 1986. The adoption rate of new technology machines accelerated after 1982: while the ratio of NCMR in total metal cutting machine tool acquisition was, on average, 7 per cent between 1976 and 1981, it increased to 18 per cent between 1981 and 1986; the NC acquisition made during the past decade now accounts for half the NC inventory.

In the United States of America (Figure 27), in 1988 the total number of NC machine tools had more than doubled since the inventory carried out in 1983.

One of the findings of the latest inventories has been the accelerated pace of acquisition of NC machines by small- and medium-scale enterprises. While large establishments were the first to experiment with NC machines, the advent of highly "user-friendly" manual data input NC and off-line programming systems have made NC a much more attractive prospect for

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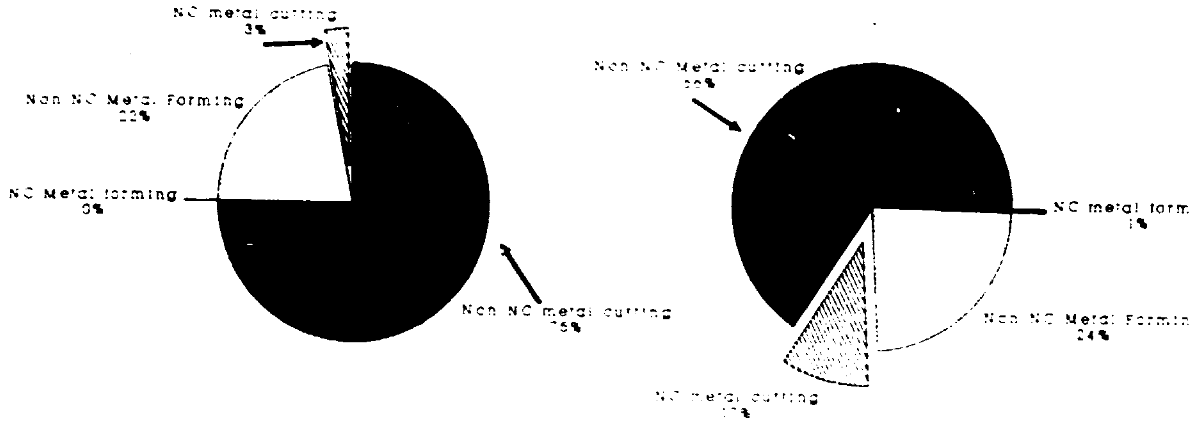
(42) In 1952, 1958, 1963, 1967, 1973, 1981 and 1987. Comparisons between inventories are difficult. The scope of the inventory may change, for example, in 1987, and 1981 the inventories concentrated on the machinery and related industries whilst previous ones covered all manufacturing industries; machine age categories are sometimes inconsistent from one inventory to the next.

Figure 25: NC diffusion in Japan engineering industries

In per cent of total installed capacity

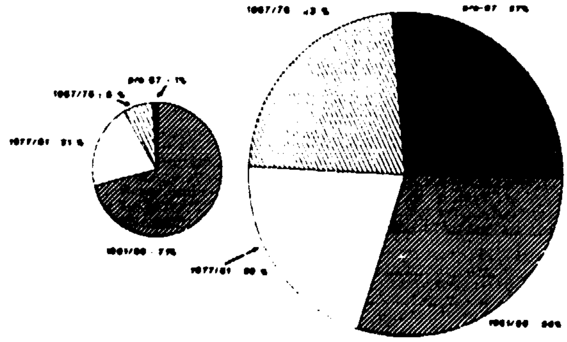


1981
Total : 747 723 units

1987
Total : 792 975 units

Source: MITI.machine-tool inventories

Figure 26: Machine tools installed by period of acquisition in the United Kingdom (1987)

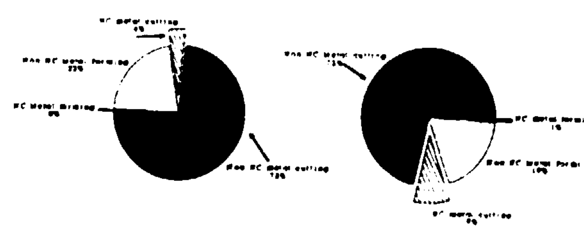


Total number of NC 62416

Total number of MT : 748 000

Figure 27: NC diffusion in the United States engineering industries

In per cent of total installed capacity



1983
Total 2 191 000 units

1988
Total 2 326 000 units

Source American Machinist

smaller companies.

In the US inventory it was found that 63 per cent of NC machine tools are in firms with 1-19 and 20-99 employees. A similar evolution has taken place in the United Kingdom where 54 per cent of NC machines can be found in plants with less than 100 employees. In the Netherlands it was found that the greatest demand for NC machines was from small and medium-size companies who are replacing their outdated punch card or manually driven machines with (mini) computer- controlled machines.(43)

This trend is clear in the case of subcontractors. According to the British inventory, their share of NC machine tools is 22 per cent, and 78 per cent of installed capacity were acquired since 1982: *"subcontractors have quickly realized that the machining centre is a highly flexible tool. In addition to jobbing work the subcontractor can tender for continuous batch work involving additional investment only in fixtures and programming. There is no need to tie up capital in dedicated machining systems to win such work"*.(44)

The diffusion among small- and medium-scale enterprises could be expected on the basis of "technological paradigm" considerations: NCMT offering economies of scope which allow to alleviate the lack of economies of scale. However this need not always be true as can be seen in the case of Italy(45) where it appears that the main users were large firms operating in mass production like automobile and electrical appliances. To explain this contrasting trend a survey was undertaken among 4000 firms which has shown that successful adoption of flexible automation involves a long learning process, tiring reorganisational procedures and strategy reallocation processes which are more easily possible for large firms or smaller enterprises operating in high technology sectors and accustomed to advanced electronics technology. The greatest difficulties seem to be of an organizational type, linked to the integrated and integrating nature of the new technologies; they require integrated production planning and design system, new professional figures.

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(43) A. J. Van Duren, Technovation 1989.
(44) Metalworking production. The sixth survey of machine tool and production equipment in Britain.
(45) Presentation of Pr Camagni, Meeting of International Experts for a Programme of Industrial Automation of the Capital Goods Industry of Latin America. UNIDO, Vienna, December 1989.

2.3.2 Sectoral analysis

The distribution of NCMT (both metalcutting and metalforming) among the main engineering industries shows that in all the three countries the greatest number of NCMTs can be found in the general machinery sector (ISIC 382) (Table 32). However, the pace of diffusion has been strongest in the case of the transport equipment sector, where in 1988 31 per cent of NCMT could be found in Japan (23 per cent in 1981) and 22 per cent in the United States (15 per cent in 1983). Diffusion of NCMT in the electrical machinery sector has also been very rapid.A survey made in Germany (F R G) in 1987/88 showed that about half of the enterprises used CNC machines.[46]

In the case of the United Kingdom, Japan and France, it is possible to analyze the diffusion of NCMT at a more desegregated level and to measure the level of automation in engineering industries at a three digit level. This allows an economic assessment of the impact of NC in the different branches.

The sixth survey of machine tools in the United Kingdom takes into consideration fifteen subsectors classified according to the SIC category. (Table 33).

The mechanical engineering sector accounts for almost half of the NC machine tools, and within this sector, ordnance, transport and mechanical equipments (SIC 329/326/328) have the highest number of machines.

The machine-tool subsector which has been a leader in the acquisition of NC tools (16% of wl ch were acquired in the years 1967-76) continued investing heavily in NC with 61 per cent of the park installed since 1981.

Motor vehicles and parts, where transfer lines and special purpose machines were the norm, acquired NC to respond to the new technological imperative in terms of flexibility. The aerospace industry had the highest ratio of NC (11,6 per cent) in its installed park.

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(46) R. Schultz-Wild and alii: An der Schwelle zu CIM Koln, RKW Verlag cited in K-H Ebel: Computer Integrated Manufacturing, ILO Geneva 1990.

Table 32: Diffusion of the stock of NCMT by sector (Japan, U.S.A) (in units)

	Japan		United States
	1981	1987	1988
metal cutting			
general machinery	11810	26267	115432
electrical machinery	3611	11566	25055
transportation equipment	6017	20579	45865
precision machinery	1796	3347	2713
metal products			14899
miscellaneous	2430	4407	504
	25664	0 66166	204468
metal forming			
general machinery	392	1030	6558
electrical machinery	656	1243	5153
transportation equipment	262	972	2658
precision machinery	24	82	134
metal products			3130
miscellaneous	395	762	215
	1729	4089	17888

Table 33: Sectoral diffusion of NCMT in the United Kingdom (in 1987)

	Number of N.C.M.T. (1)	% share in total stock of NCMT (2)	Total Number of MT (3)	% share in total stock of MT (4)	Value Added* 1986 (5)	(6) (1)/(5)	(7) (2)/(4)
foundries, forging, stamping	1738	3.4%	42426	5.6	1168	1.5	.56
bolts,nuts, springs etc..	826	1.6%	23795	3.1	533	1.5	.47
metal doors, windows	4897	9.7%	107276	14.2	2596	1.9	.62
Manufacture of metal goods	7461	14.8%	173497	22.9			
industrial plant, steelwork	985	1.9%	26765	3.5	1417	.7	.50
machine tool&engineering	2953	5.8%	46605	6.2	800	3.7	.87
agricultural machinery	2603	5.2%	40130	5.3	1576	1.7	.89
textile,food,chemical, mach.	3333	6.6%	43551	5.6	1703	2.0	1.05
ordnance,trasp equip,mech	14188	28.1%	169026	22.3	2862	5.0	1.15
Mechanical engineering	24062	47.6%	326077	43.1			
electrical equipment, appliances	3163	6.3%	61964	8.2	2298	1.4	.70
electronic, telecommunications	4105	8.1%	43865	5.8	4682	.9	1.28
Electrical and electronic	7268	14.4%	105829	14.0			
motor vehicles and parts	4492	8.9%	70268	9.3	4308	1.0	.87
aerospace	4053	8.0%	34979	4.6	3378	1.2	1.58
transport equipment	1046	2.1%	18486	2.4	749	1.4	.77
Other transport equipment	5099	10.1%	53465	7.1			
instrument engineering	2141	4.2%	27247	3.6	669	3.2	1.17
TOTAL	50523	100.0%	756383	100.0	28739	1.8	1

Sources: Columns (1), (3) from the Sixth survey of machine tools and production equipment in Britain published by Metal Working Production 1988.
*Measured in sterling millions.

Table 34: Data on diffusion of NCMT in France

	Number of N.C.M.T. (1)	% share in total stock of NCMT (2)	Total Number of MT (3)	% share in total stoc of MT (4)	Value Added 1986 (5)	(6) (1)/(5)	(7) (2)/(4)
Foundry,	580	1.67	13228	2.15	13.93	41.6	.78
Structure metal products	11678	33.62	190599	30.98	68.98	169.3	1.09
Agricultural machinery	505	1.45	13178	2.14	7.41	68.1	.68
Machine tool	2781	8.01	33995	5.53	8.39	331.3	1.45
Machinery for general industries	5856	16.86	91140	14.82	73.49	79.7	1.14
Industrial machinery	1164	3.35	19831	3.22	123.75	9.4	1.04
Electrical machinery	2537	7.30	40378	6.56	37.02	68.5	1.11
Electronic	1799	5.18	30733	5.00	54.74	32.9	1.04
Motor vehicle	3867	11.13	116105	18.87	81.13	47.7	.59
Railroad	236	.68	2946	.48	4.08	57.8	1.42
Shipbuilding and repairing	102	.29	4737	.77	6.10	16.7	.38
Aircraft	1904	5.48	23834	3.87	21.91	86.9	1.41
Professional and scientific	1726	4.97	34436	5.60	20.82	82.9	.89
TOTAL*	34735	100	615140	100	521.75	66.6	1

Compiled from BIPE inventory 1987.

Metal goods manufacture, where small and medium establishments are in great number, has experienced the most rapid diffusion of NC machines, with 82 per cent acquired between 1982 and 1986.

For an economic analysis of the impact of NC, the characteristics of the different subsectors have to be taken into account. Two indicators(47) may be determined to measure the intensity of NCMT utilization; namely:

(i) the average share of NCMT in the total stock of machine tools in the subsector, that is, the ratio between the number of NCMT installed in the subsector to the total number of machine tools installed in this subsector. This shows the likelihood of choosing NCMT instead of other machine tools for the subsector.

(ii) the ratio of the number of NCMT installed to the value of production (value-added) of the subsector which is an indicator of the importance of NCMT in the value-added process.

The subsectors have been mapped out in a plan (Figure 28) where the vertical axis shows the normal share of NCMT and the horizontal axis the number of NCMT per value-added. The further the north east of the plan, the greater is the impact of NCMT.

-The three subsectors in the Northeast quadrant are textile and food industry machinery, instrument, ordinance and transport equipment.

-In the Northwest, one finds subsectors with high intensity use of NCMT but where machining plays a minor role: which is the case of electronics and aerospace.

-In the Southeast, one find machine tools, agricultural machinery and metal doors and windows.

-In the Southwest are those sub-sectors not much affected by automation: industrial plants and steelworks, foundries and stamping, electrical equipment and appliances, motor vehicles and parts.

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(47) Following the methodology proposed by Edquist and Jacobsonn in Flexible Automation the global diffusion of new technology in the engineering industry, 1988.

Figure 28: Diffusion of Numerical Control Machine Tools in U.K. Industries

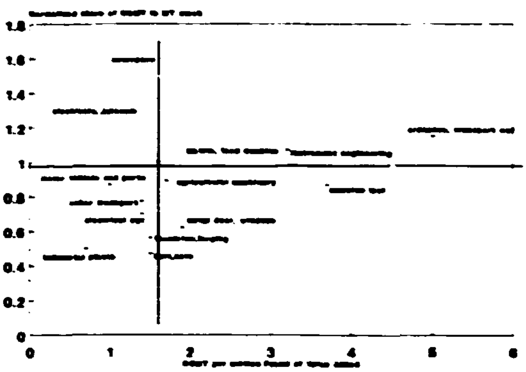


Figure 29: Diffusion of Numerical Control Machine Tool in France in 1987

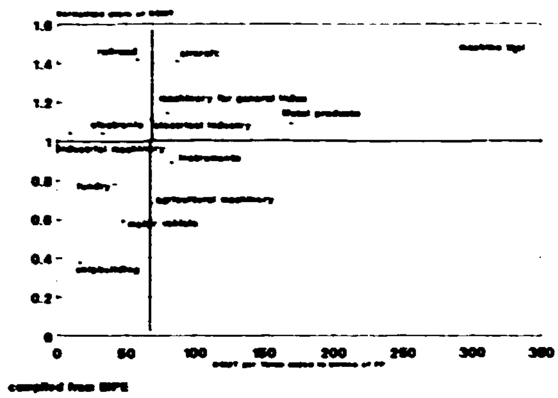
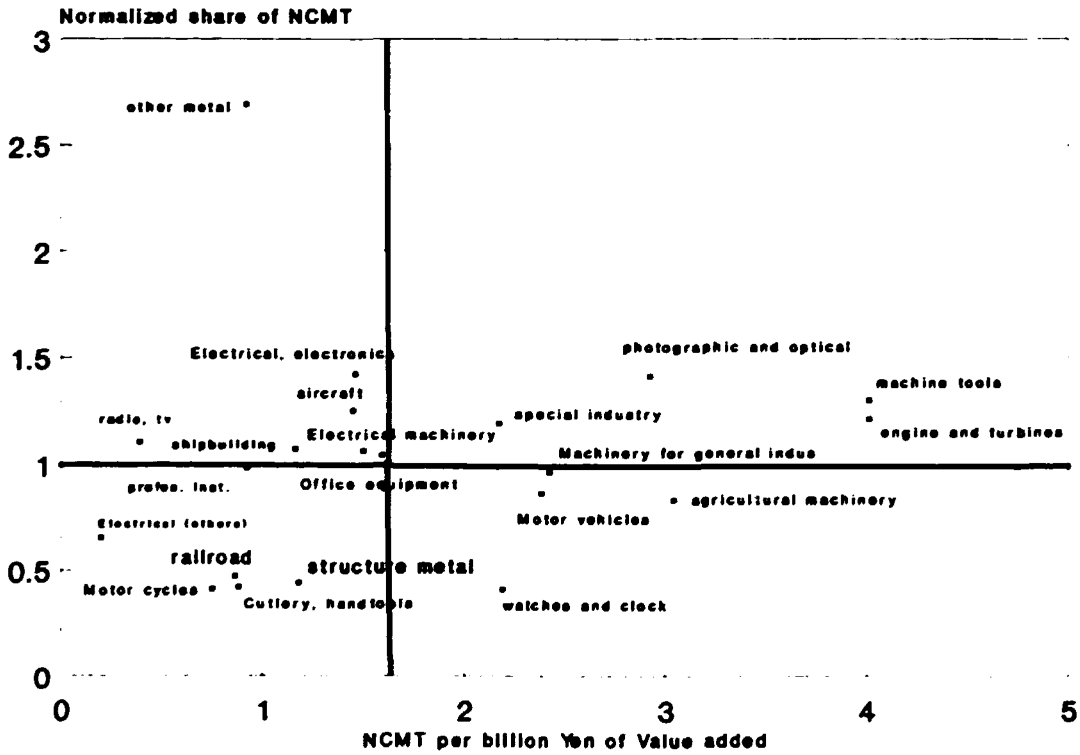


Figure 30 : Diffusion of Numerical Control Machine Tools in Japan



The survey of machine tools in France takes into consideration thirteen subsectors classified according to the French classification.[48] (Table 34)

The largest number of machine tools and NCMT are found in the metal products sector followed by motor vehicle and machinery for general industries.

The machine-tool subsector which has been a leader in the acquisition of NC tools (16% of which were acquired in the years 1967-76) continued investing heavily in NC with 61 per cent of the park installed since 1981.

Metal goods manufacture, where small and medium establishments are in great number, has experienced the most rapid diffusion of NC machines, with 82 per cent acquired between 1982 and 1986.

Figure 29, based on the previous methodology, illustrates the diffusion of NC within the different branches:

-The three subsectors in the Northeast quadrant are machine tool industry, metal products, aircraft, machinery for general industry.
-In the Northwest, one finds electronics and railroad equipment.
-In the Southeast, one finds instruments and agricultural machinery.
-In the Southwest: foundries, electrical equipment, motor vehicles, shipbuilding.

The trends in the sectoral diffusion of NCMT in Japan, a pacesetter in industrial competitiveness, are of great interest to all countries.

The largest numbers of NCMT (Table 35) can be found within the motor vehicle industry (29 per cent in 1987), followed by machinery for general industries (such as pumps, conveyors, air conditioning apparatus, elevators), and metal and wood-working machinery (which includes the machine tool industry). It is within other metal products (screws, bolts and nuts) followed by machine-tool industry and the photographic and optical industries

(48) Nomenclature des activites productives.

Table 35: Data on diffusion of NCMT in Japan

Manufacture of	Number of N.C.M.T. (1)	% share in total stock of NCMT (2)	Total Number of MT (3)	% share in total stoc of MT (4)	Value Added 1986 (5)	(6) (1)/(5)	(7) (2)/(4)
Cutlery, handtools, general hardware	361	.53	7745	1.26	408	.88	.42
Furniture and firture		0		0			
Structure metal products	258	.38	5223	.85	219	1.18	.44
Other metal products	2846	4.15	9437	1.54	3108	.92	2.69
Engines and turbines	1607	2.34	11897	1.94	401	4.01	1.21
Agricultural machinery	1114	1.62	11935	1.95	366	3.04	.83
Metal and wood working machinery	7083	10.32	48636	7.94	1766	4.01	1.30
Special industrial machinery	4875	7.10	36437	5.95	2245	2.17	1.19
Office, computing machinery	5135	7.48	44067	7.19	3222	1.59	1.04
Machinery for general industries	10872	15.84	100948	16.47	4490	2.42	.96
Electrical machinery	3712	5.41	31333	5.11	2479	1.50	1.06
Radio, television, communications	3355	4.89	27174	4.43	8592	.39	1.10
Electrical, electronic appliances	2332	3.40	14700	2.40	1597	1.46	1.42
Electrical apparatus others	407	.59	5621	.92	2073	.20	.65
Shipbuilding and repairing	809	1.18	6764	1.10	699	1.16	1.07
Railroad	100	.15	1882	.31	116	.86	.47
Motor vehicles	20123	29.31	210090	34.28	8455	2.38	.86
Motor cycles	106	.15	2322	.38	141	.75	.41
Aircraft	399	.58	2845	.46	276	1.45	1.25
Professional and scientific	595	.87	5439	.89	648	.92	.98
Photographic and optical	1775	2.59	11261	1.84	607	2.92	1.41
Watches and clocks	790	1.15	17115	2.79	361	2.19	.41
TOTAL*	68654	100	612871	100	42269	1.62	1

Compiled from MITI inventory
* different total number of NCMT and MT due to conversion problems between ISIC and Japanese industrial codes.

Table 36: Evolution of the stock of NC/CNC machine tools (000s)

	USA	USSR	JAPAN	ITALY	FRG	UK	FRANCE
around 1970	20	11	5	1	2	3	
around 1975	40		14	3			4
around 1980				11	25		10
around 1985	103			55	64		35
estimate 1990	240		100	100	100	80	60

that one finds the highest share of NCMT among installed machines in the sectors. Those sectors where NC machines are relatively numerous are, inter alia, aircraft, engines and turbines, special industrial equipment, consumer electronics, office and computing equipment.

Figure 30 illustrates the impact of NCMT in the different subsectors:

-The subsectors in the Northeast quadrant are metal and wood machinery (including machine tools), engines and turbines, photographic and optical equipment and special industry machinery and machinery for general equipment.
-In the Northwest, one finds subsectors with a high intensity use of NCMT but where machining plays a relatively minor role: as is also the case of other metal products, consumer electronics, electrical and electronic appliances, shipbuilding .
-In the Southeast, one finds agricultural machinery, motor vehicles, watches and clocks.
-In the Southwest are subsectors not much affected by automation: cutlery and handtool, structural metal products, motor cycles, railroad equipment, electrical apparatus.

One should be cautious in reaching conclusions from these three examples. The position of each subsector is relative to the country: the degree of automation in Japan being more advanced than in the United Kingdom. Nevertheless some similar conclusions do appear, concerning the industries less affected by automation; i.e. handtools, electrical apparatus, structural metal products which are among the most common engineering sectors in developing countries.

The machine-tool industry is one of the enginnering sectors where the diffusion of NC will have the more pronounced impact. (Box 14).

2.4 Forecast for the 1990s

Table 36 provides an estimate of the population of NCMT in 1990. As can be seen growth rates for CNC machines in Europe has varied between 10 and 20 per cent per year. While the largest number of NC machine tools can be found in the United States, it is apparently in Italy where their share is the highest among

Box 14: <u>NC diffusion in the machine-tool industry</u>

While, in general, flexible automation is enhancing the competitiveness of small firms, changes in the size distribution in the specialized industries such as machine-tool industries may tend to be biased towards the bigger sized classes because of R&D indivisibilities and economies of scope based on electronic flexible manufacturing systems.

The inventory in Japan has illustrated the introduction of NCMT in the machine tool industry. The productivity has been greatly enhanced and production runs are long by Western standards. Japanese firms are regarded as the pioneers of mass production techniques in the machine-tool industry. For instance, Star Micronics was building 50 CNC sliding headstock lathes per month with 230 personnel in 1984; by 1988, a new factory equipped with 100 machine tools (80 per cent NC) produced 100 machines with 63 employees with a capacity target of 130 units per month: a tenfold increase in productivity.

Changes in organization have concerned the introduction of modular construction which is strengthened by the need of the metal-working industry to machine a wide range of parts in small and large batches, with the ability to change over quickly from one family part to another. This can best be done by a system which allows various configurations of machining systems to be built up from a range of standard modules rather than by the use of inflexible machine parts. Considerable success has been achieved in using modular units for building grinders for high volume production, but a wider application of the concept to embrace lathes, milling and drilling machines has yet to be established. As more industries turn to group technology, machine tool builders will increasingly adopt modular construction concepts which allow short lead times, flexibility in final machine configuration, low inventory and larger batch quantity.

the total number of machine tools (15 per cent) followed by France, Japan (10.7 per cent, and 13.4 per cent among metal cutting machine tools). According to the latest Japanese inventory (1987) the pace of installing the newest machine tools has started to abate.[49]

The diffusion of NC as of any other technological innovation can be described by an S-shaped curve where the three distinctive parts are: initial expansion (rising curve), transition zone (inflection point) and saturation (falling curve).[50] This pattern can be used in order to forecast[51] the maximum performance of the technology and its saturation point measured as the percentage of total number of machine tools installed.

Forecasts which were based on the inventories statistics led to unreliable results[52] and in order to circumvent this difficulty, methods based on consumption data have been utilized: it has been shown[53] that the evolution of the share of NC in consumption could be considered as a leading index of the evolution of the share of NC in installed capacity and that the saturation level of NC in installed capacity was equal to that in consumption with some time lags.

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(49) In 1988 and 1989, domestic sales of NC machine tools have reached 70000 while the replacement rate was 78 per cent.

(50) Several equations can be used to represent this pattern, among which Pearl equation where $D(t)=1/(1+Ae^{-kt})$, von Bertanlaffy $D(t)=(1+Ae^{-kt})^3$. In each of these expressions A can be interpreted as the value of D(0) while k measures the dynamism over time.

(51) P.F. Gonod: "<u>Technological forecasting: principles and analysis of methods</u>" IPCT(107) SPEC, UNIDO February 1990.

(52) Tchijov I. "<u>CIM diffusion, the case of NC machine in the US metalworking industries</u>" IIASA WP-87-77 September 1987.

(53) A. Tani: "Saturation level of NC machine-tool diffusion" in J.P. Ranta, editor: "<u>Trends and impacts of Computer integrated manufacturing</u>" Proceedings of the second IIASA annual workshop on Computer Integrated Manufacturing: Future trends and impacts IIASA Laxenburg 1989.

-Based on NC share in production of machine tools[54] from 1970 to 1988, it[55] has been forecasted that the saturation level will be 34 per cent for metal cutting; then making estimates for the replacement years, it has been then shown that NC share in installation will show their biggest increase from 1985 to 1995 and approach saturation level after 2000 (Figure 31) with 34 per cent of machine tools installed being NC. In the case of establishments of more than 50 employees the NC share in installation could reach about 40 per cent.

-Applying the same methodology to the US consumption data, the same pattern of diffusion, with some time lag with Japan is found. It appears that NC in installed capacity could reach 30 per cent in 2005.

These forecast mean that the strongest diffusion of NC machine tool will happen during the next decade and it should have a significant impact in the coming years on the competitiveness in the engineering industries.

3 System integration

Whereas a NC machine tool is a substitution innovation, a flexible manufacturing system appears as a radical innovation, a way to do new things. The gains attainable through systemic integration of NC machines are considerably greater than those attained through the addition of stand-alone equipments and a FMS has been described as a miniature factory.[56]

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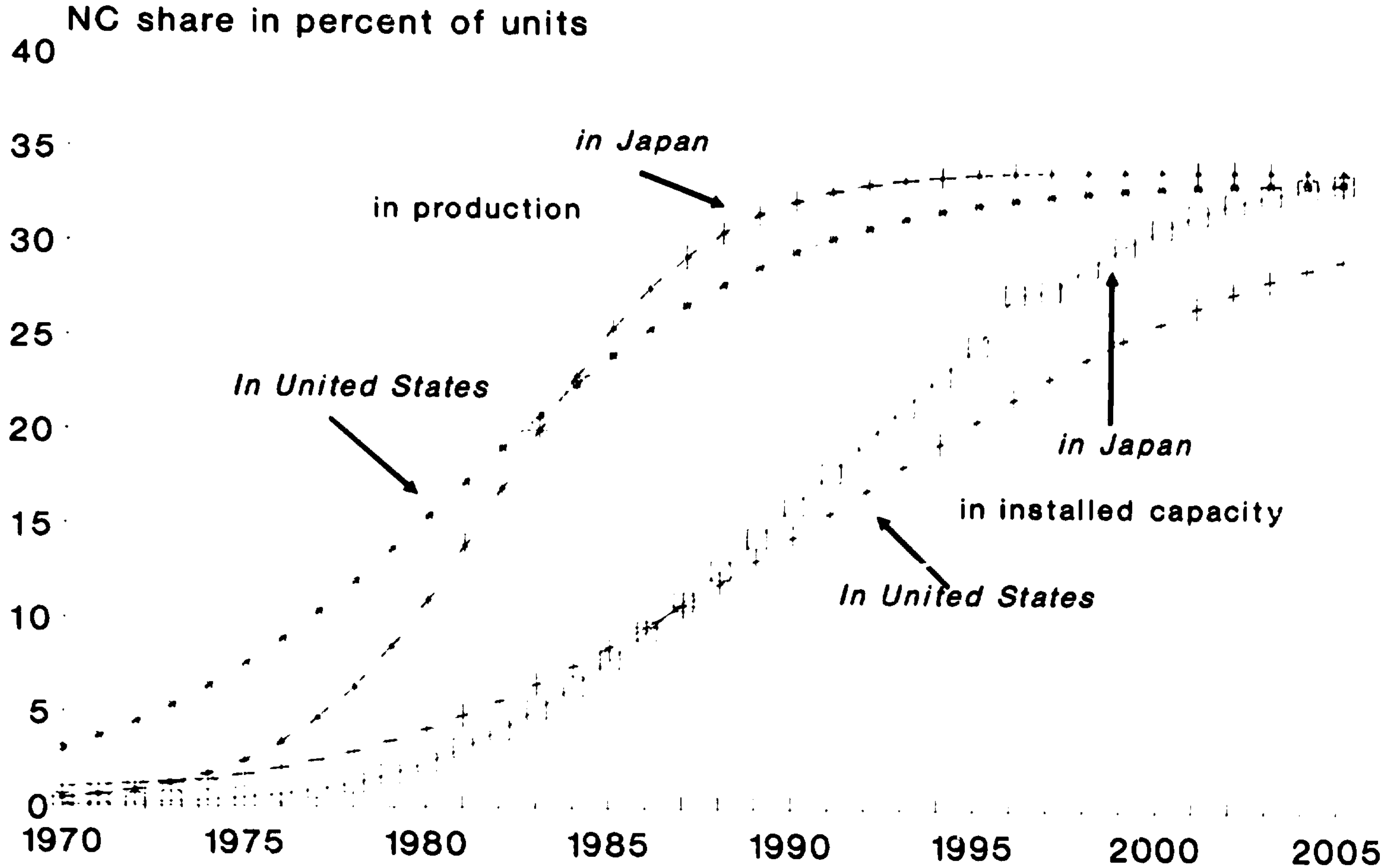
(54) Which is closely similar to the NC share in consumption.

(55) A. Tani: "Saturation level of NC machine-tool diffusion" in J.P. Ranta, editor: "Trends and impacts of Computer integrated manufacturing" Proceedings of the second IIASA annual workshop on Computer Integrated Manufacturing: Future trends and impacts IIASA Laxenburg 1989.

(56) Bessant at the meeting of international experts on a programme for industrial automation of the capital goods sector in Latin America.

Figure 31 Forecast for NC share in production and installation

for metal cutting machine-tools



For Japan: IIASA; for USA Computed

3.1 Flexible manufacturing cells and systems

Most definitions (Box 15 and Box 16) distinguish between systems according to the number of machines linked together by material handling systems and their capacity to respond to multiple processing needs of different shapes and dimensions.

However, the number of machines used in a system cannot be considered as the dividing line between a flexible manufacturing cell and a flexible manufacturing system. These two systems are working under quite different principles (Figure 32).

-The FMC is based on a synchronization principle: at any given time, several machines are processing the working piece.

-The FMS is based on a coordination principle: each of the machines is processing the working piece at a time. The transfer between the different machines can be organized under two principles:

- -flow shop: the workpiece goes from one machine to the other as in a transfer line
- -job shop: it is then possible to combine in different manners the machine utilization.

3.1.1 Flexible manufacturing cells

The trend towards FMC is fuelled by the increasing power made available on "one hit" machines. Turning centres are the best examples, with capability for second operation such as slotting, milling and drilling; milling/machining centres have developed turning capabilities.

The number of machining centres is an indication of the diffusion of FMC. In the United States of America, it grew from 17,000 in 1978 to 24,000 in 1983 and sharply increased to 53,585 in 1988;[57] a similar expansion was recorded in the United Kingdom (5,900 to 10,500) while in Japan the total number was 14,000 in 1987. (Table 37).

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(57) For the period 1988-1993 the market for machining centres is expected to increase by 5.3 per cent per year reaching US$700 millions in 1993.

Box 15: <u>FMS, FMC definitions</u>

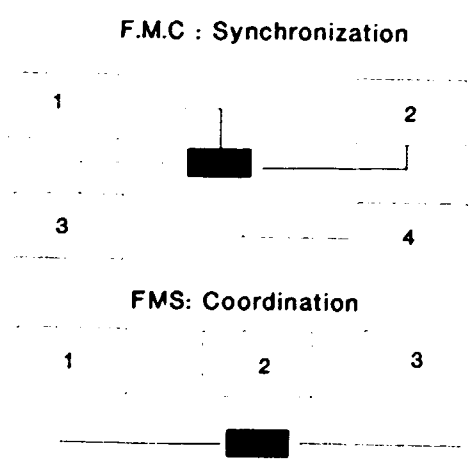
<u>Flexible manufacturing modules</u> consist of a stand-alone NCMT, material handling equipment such as robots or a pallet charger as well as some kind of a monitoring system. The FMM can be incorporated into a module in a larger system.

<u>Flexible manufacturing cell</u> consists of at least two conventional and/or NCMT and includes a material handling device as a robot serving a number of machine tools standing on line or circle, or automatic pallet changers in conjunction with automatic transport between the NCMTs.

<u>Flexible manufacturing systems</u> contain several automated machine tools of the universal or special type and/or flexible manufacturing cells, and if necessary, further manual or automated workstations. They are interlinked by an automatic workpiece flow system in a way which enables the simultaneous machining of different workpieces which pass through the system along different routes.

<u>Flexible transfer line</u> contains several automated universal or special purpose machine tools and further automated workstations as necessary, interlinked by an automated workpiece flow system according to the line principle. A flexible transfer line is capable of simultaneously or sequentially machining different workpieces which run through the system along the same path.

Figure 32 FMC and FMS



adapted from Hollard, Margirier

Box 16: Description of a FMS

In most FMS installations, incoming raw workpieces arrive at a workstation where they are positioned into fixtures on pallets. When information is entered, the FMS supervisor (computer) takes charge, performing all the necessary operations to completion.

The supervisor first sends a transporter to the load/unload station to retrieve a pallet. The loaded pallet then keeps moving in a loop until a machine becomes available to perform the first operation. When a shuttle (a position in the queue) becomes available, the transporter stops and a transfer mechanism removes the pallet.

Parts received by a machine must be accurately located relative to the machine tool spindle. The inspection to ascertain this can be done manually, using standard instruments, or by coordinate measuring machines. The appropriate machining offsets are calculated from the measurements and communicated to the supervisor.

Meanwhile, the supervisor determines whether all of the tools required for the machining operations are present in the tool pocket and requests needed tools from either off-line tool storage or a tool crib/tool chain within the system. When all the required tools are loaded, the supervisor downloads the NC part programme to the machine controller from the FMS control computer.

The process of making sure that the part is, in fact, what the computer thinks it is is termed "qualifying" the part: it includes making sure that all previous operations have been completed, that the part is dimensionally within tolerance limits, and that it is accurately located.

When the set-up activities are completed, machining begins. The FMS monitors the tool during matching. If it breaks, a contingent procedure is invoked. Compensating corrections for any deviation are made during machining. Adaptive control in FMS is still very rudimentary and technically quite difficult with present-day technology.

The finished, or machined part is moved to the shuttle to await a transporter. After being loaded onto the transporter, the pallet moves to the next operation, or else circulates in the system, or is unloaded at some intermediate storage location until the machine required for the next operation becomes available.

The computer controls the cycles, collects statistical and other manufacturing information from each station for reporting systems.

Adapted from Jaikumar: "Japanese flexible manufacturing systems, impact on the United States, Japan and the world economy" in International Journal of Theory and Policy, Volume 1, Number 2 1989.

Table 37: Diffusion of machining centers in units

	1983	1987	1988
Japan		14610	
United States	24000		53585
United Kingdom	4902	10354	

Sources: National Inventories Reports

3.1.2 Flexible manufacturing systems

Because of the variety in definitions and of the inadequacies in the international collection of data, estimates for the stock of installed FMS vary widely and the pattern of their diffusion is not well documented. The total number of systems installed has increased from 80 (1980) to 1200 in 1989 and according to IIASA[58] projections it could reach 3000 in 2000. Most of the systems installed having at least two CNC machines, one can estimate that the total stock represent less than 1 per cent of CNC installations world wide.

The first FMS was built in the United States of America in 1970 and there was a steady but non-spectacular growth rate of installed capacity until 1982, at which point the number of systems in use doubled to reach 200 in 1984.[59] Sales of FMS in 1984 amounted to US$120 millions (half in Europe) and in 1988 European industry was spending US$620 millions on FMS according to Frost&Sullivan and total sales could reach US$1 billion by 1991.[60]

According to IIASA the total number of FMS has been estimated at 1200 in 1989. (Table 38) The two main users were Japan (167)

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(58) In ECE Seminar on CIM, Sofia, September 1989.
(59) J. Bessant, B. Haywood, H.Rush Integrated automation in batch manufacturing. Paper prepared for the OECD, Directorate for Science, Technology and Industry, Paris, 1987.
(60) Metalworking Production: "Europe to treble FMS by 1991", February 1988.

Table 38: <u>Distribution of fully integrated flexible manufacturing systems</u>
estimates (units)

	1980	1983	1985	1987	1988	1989	2000 projection
Japan	28	135		254		167	
USA	6-14	15-31				137	
United Kingdom	3	4				93	
Germany (F R G)	10	13				74	
France	2	13				67	
USSR						56	
Italy		12			25	37	
Sweden						36	
German Democratic Rep.			11			28	
Czechoslovakia						23	
Estimates world wide	80	>100				1200	3000

<u>Sources</u>:
1980-1983: Bessant
Japan figures: 7th Inventory (1987)
Italy: Technovation, 9 (1989) page 497
IIASA FMS World Data Bank (1989)

Table 39: <u>Sectoral distribution of FMS</u>

<u>in Japan</u>		
general machinery	169	67%
electrical machinery	42	17%
transportation equipmen	39	16%
others	1	0%
	251	

<u>in Europe</u>	U.K.	S	FRG
machine building	26%	38%	69%
Motor vehicles and engi	30%	16%	4%
aerospace	12%		4%
electrical electronics	8%	8%	
subcontracting	24%	38%	6%
	100%	100%	83%

<u>Source</u>: Haywood and Bessant 1987
MITI 1987

and the United States of America (137): they are followed by Germany (F R G), the United Kingdom and France.

The diffusion of FMS has tended to be restricted to selected industries (Table 39) where they are used on a narrow range of operations for the production of particular components (e.g. engine manufacturing and transmission in the case of automobiles). These industries remain the main markets for FMS: according to IIASA, about half of the systems installed are used in the transport equipment (car, tractor and aerospace), the second main user is non electrical machinery (mainly machine building) and the third electrical machinery. In the USSR, half of Soviet FMS's were used by the machine tool industry itself, 25 per cent in the automotive industry and 10 per cent in the electrical machinery.[61]

The motor vehicle industry dominates forecast sales based on current proposals. Workpiece families manufactured are cylinder heads, brake drum housings and engine components. There is some extension of the scope of utilization of FMS to assembly in Italy, Japan and the United States of America thus bringing FMS into operation in the largest area of activity.[62] New groups of users are also emerging in sectors such as pumps, marine components, valves and hand tools. FMS acquisitions were restricted to large firms, however diffusion among subcontracting firms has begun in industrialized countries.

When successfully implemented, FMS can dramatically reduce cost of production as a result of increased machine utilization, reduction in the setting up time and the lead time (machining time necessary to complete a cutting operation), savings in stocks, works in progress, capital employed and labour costs.

In his detailed study on 95 flexible manufacturing systems installed in the United States and Japan, Jaikumar [63] compares

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(61) S. Sipos and H. Sitarska: "Technological and organizational change: a challenge to Eastern Europe", IDS Bulletin 1989, vol 20 number 4.

(62) Hoffman: "Technological Advance and Organizational innovation in the engineering industries", Industry Series Paper, Number 4, March 1989, The World Bank.

(63) R. Jaikumar: Post-industrial manufacturing Harvard Business Review November-December 1986.

the performance of a Japanese factory before and after the introduction of total flexible automation (Table 40):

-average processing time per part decreases by a factor 3
-floor space is diminished by 2.5
-personnel requirements in three shifts decreased dramatically from 195 to 39

Table 41 documents the manpower requirements of various metal cutting systems for metal cutting operations in an American and Japanese factory. If it took 100 people in a conventional Japanese factory to make a certain number of parts it would take 143 in a conventional US factory to make the same number of identical parts; however it would only take 43 in a Japanese FMS equipped factory. The largest manpower reduction appears in manufacturing overheads, from 64 to 5, while in engineering the number of workers falls from 34 to 16. One consequence of this reduction is to change the composition of the work force: engineers outnumber production workers 3 to 1 in a FMS-equipped factory. This signals a fundamental change in the environment of manufacturing: *"flexible automation shifts the arena for competition from running the plant to planning"*.[64]

FMS population can be divided into two large groups: cheap systems costing less than US$5 millions, which are the most widely used, and expensive ones counting more than that.

Investing in FMS is often a painful process and previous forecasts concerning their diffusion have proved to be over optimistic because they underestimated the following:

-technical problems in terms of interface software and network organization

-organizational problems: FMS cannot be considered as a technological fix to an inefficient plant. Large companies which had invested considerably in factory automation have had difficulties to make these systems cost effective and technically reliable. In a comparative study[65] (Table 42) it was found that a typical Japanese FMS was able to produce nearly ten times more different

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(64) Jaikumar, Harvard Business Review.
(65) Jaikumar, Harvard Business School Review, 1985.

Table 40: <u>Performance of a Japanese factory before and after introducing FMS</u>

	before	after
Types of part	543	543
Number of pieces	1120	1120
Floor space (sq meter)	16500	6600
Equipment per system	90	43
Personnel per system (3 shifts)	195	39
Average processing time in days	91	30

Tabie 41: <u>Comparison of manpower requirements for metalcutting operations to make the same number of parts in the United States of America and Japan</u>

	conventional system		FMS
	USA	Japan	Japan
Engineering	34	18	16
Manufacturing overhead	64	22	5
Fabrication	52	28	6
Assembly	44	32	16
Total number	194	100	43

Table 42: <u>Comparison of FMS studied in the United States of America and Japan in 1984</u>

	USA	Japan
System development time in years	2.5 to 3	1.25 to 1.75
Number of machies per FMS	7	6
Types of parts produced	10	93
Annual volume per part	1727	258
Number of parts produced per day	88	120
Number of new parts introduced per year	1	22
Number of systems with untended operations	0	18
Utilization rate (two shifts	52%	84%
Average metal cutting time per day (in hours)	8.3	20.2

<u>Source</u>: R. Jaikumar, Post-industrial manufacturing Harvard Busines Review, Nov/Dec 1986.

parts than the equivalent US system and its utilization rate (metal cutting time over total time) was 84 per cent instead of 52 per cent in the US. The reasons for this difference laid in the design and operation of the system. The development time of the systems surveyed in the United States took in average 2.5 to 3 years and about 25000 man hours to conceive, develop, install and get running while in Japan similar tasks necessitated 1.5 to 1.75 years and 6000 man hours. Contrary to Japanese experience, in the US firms design was separated from execution; skilled machinists who installed the systems were replaced by under-trained operators who failed to utilize the FMS improved capabilities.(66)

-problem diagnosis difficulties: an FMS has all the problems common to NC machines but it also lacks the stand alone NC machine's constant attention from a machine operator who can compensate for small errors. Determining the source of an "out of tolerance" problem in an integrated FMS can be very difficult.(67)

Due to all these difficulties, there has been a shift in the attitude of firms in favor of a step-by-step approach, starting with flexible manufacturing cells, the islands of automation which will be progressively linked with work transport and tool management to form FMS as part of an overall CIM operation.

3.1.3 Computer integrated manufacturing

Technological trends such as NCMT and FMS, were confined to the sphere of manufacturing, this stage of automation could be followed by another which will concern the integration between design, production and management. Computer Integrated Manufacturing was pioneered in the United States of America in the late 1970s by Boeing, General Motors among others.

(66) A survey of FMS installed in the United Kingdom found that 18 out of a total of 27 installations could be described as dedicated systems, Machinery and Production, 75th Anniversary issue.

(67) Jaikumar: From filing and fitting to flexible manufacturing: a study in the evolution process control Havard Business School working paper 1988-045.

With CIM, networks connect every microprocessor, robot and programmable controller in a factory, feeding information from all stages of production into one computer.[68] In the design department, the diffusion of Computer Aided Design system, first used for drawing preparation, allows conversion of ideas and modifications into a full set of engineering drawings. These systems can generate the necessary data for computer controlled production equipment via various Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) post-processors. Similarly, the various discrete activities in production management are now available as modules for integrated suites or management software which draw upon the same central database. The movement extends beyond the operation of the firm itself to its environment and can involve the supply chain and the distribution and marketing network.

The concept of an all- embracing computer integrated manufacturing environment could be exploited in the 1990s and beyond to achieve a single integrated business system.[69] According to some estimates the total spending on factory automation could rise to US$30 billions in 1995 with Japan and the United States being the forerunners. A leading factory automation company has predicted that 70 per cent of Japanese company will have "some kind" of CIM within ten years up from about 30 per cent in 1990.[70]

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(68) Nissan put together its own version of CIM for its new luxury car the Infiniti. Called IBAS, for intelligent body assembly system, it can spot trouble and issue instructions for repairs. The company plans to build similar systems in its plants abroad (Fortune: Japan capital's spending spree, April 9, 1990).

(69) IBM's launch of its multi-vendor CIM-architecture is the largest of many signs to reinforce the message that integration can be achieved gradually.

(70) Fortune: Japan capital's spending spree, April 9 1990.

Table 43: Estimated allocation of investments in Factory automation

US$ millions	1985	1990	1995
factory computer and software	935	2500	6500
material handling systems	2000	4500	8000
machine tools and controls	3000	4800	7000
programmable controlers	50	550	3000
robots and sensors	65	660	2800
automatic transfer and equipment	800	2000	4000
Total spending on automation	6850	15010	31300

Source: Dataquest

One of the most important constraints to the diffusion of CIM is the lack of industry-wide standard in software. GENERAL MOTORS one of the largest client has pioneered the Manufacturing Automation Protocol (MAP) for the linking of stand alone equipments which is compatible with the Technical Office Protocol used by BOEING. The International Standards Organization (ISO) is promoting the Open Systems Interconnection (OSI). Moreover, much information required in the production process is not suitable for coding, computer processing and transmission.(71)

Experts disagree on the ultimate consequences of the automation. The unmaned factory was first described in 1949 by N. Wiener(72) and its introduction was then expected for the early 70. Forty years later, the worker-less factory is still within the realm of imagination.(73) Managers who dreamed of replacing human workers with robots or CNC machines find that as machines become more sophisticated, the problems of finding good workers has not gone away. The idea that the machine shop trade is dying because of automation looks as a myth: "*automation is great if you have someone to operate it and to do the*

(71) K.H. Ebel: Computer integrated manufacturing, the social dimension, ILO, Geneva 1990, pages 30-33.
(72) N. Wiener: The Human use of human beings Cybernetics and society.
(73) K. H. Ebel: L'usine automatise a besoin de la main de l'homme. Revue Internationale du Travail, 5/1989, Geneva.

brainwork".[74] It appears that the technocentric vision of the factory of the future is a dead end.[75] flexible automation can only function if its manned by highly qualified technicians and the proper mixture of persons and machines may bring more value added.

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(74) Special Report on training, American Machinist, June 1989.

(75) Cohen, Zysman : "US competitiveness suffers: the emergence of a manufacturing gap, in Translatlantic perspectives, Washington, Autumn 1988.

CHAPTER IV: IMPLICATIONS FOR DEVELOPING COUNTRIES

The evolution of the machine tool, from a noisy machine driven by men in blue overalls to an "island automation" operated by technicians and programmers has implications for developing countries which go far beyond the question of entry into (and development of) the machine-tool industry. This evolution should be considered in the context of the changes affecting the global rules of competition in the engineering industries and beyond.[1]

After an assessment of the implications of these trends on machine-tool producers, this chapter will address the questions of the impact on the engineering industries and the issue of industrial automation in developing countries.

1 Impact on machine-tool production

1.1 Entry into the machine-tool industry

In several countries the rationality of entry into the machine-tool industry was not based on economic factors alone. To measure the net benefit provided by such an investment, account should be taken of the economic returns (value added, foreign exchange benefits etc.) together with externalities such as the possibility of adaptation and improvement of technology and the training of manpower. (Box 17)

One of the most important decisions facing developing countries in the capital goods sector is the "make or buy decision",[2] taking into account the choice of a product mix and the acquisition of technology.

1.1.1 Technical Constraints

The main difficulty facing developing countries willing to enter the machine-tool industry is often less technological than economic: the lack of a sufficient domestic market and the

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(1) For instance the impact of flexible automation in the garment industry.
(2) M. Fransman: Machinery and Economic Development, Mac Millan, 1986.

Box 17: <u>Measuring the economic effectiveness of machine-tool industry in Pakistan</u>

An assessment of the economic role of the machine-tool industry has been made in Pakistan. The industry is made of 188 units with up to 20 employees, 10 medium units (21 to 100) and two large units with more than 100 employees; total sales were US$3 millions in 1987.

The study assessed the benefits in terms of employment, foreign exchange savings, value-added and measured the domestic resource costs of several products:

<u>Employment</u>. Direct employment in machine tool units was 2261, however many operations are sub -contracted: the largest operation is castings which generated 445 additional jobs, other operations (planing, gear making) have generated 91 jobs.

<u>Foreign exchange savings</u>. The cost of Pakistani machines have been estimated at one third to one fifth of those imported from industrialized countries. Local production of 77 000 machine tools over a twenty year period has represented a substantial gain for the national economy which has been estimated at US$105 millions.

<u>Value added</u> as percentage of local sales has been quite substantial: 36 per cent in the case of small firms, 41 per cent in medium firms and 51 per cent in large firms.

<u>Domestic Resource Cost (DRC)</u>. In order to assess the economic efficiency of the industry, the DRC - which measures the local costs incurred per unit of foreign exchange saved or earned- has been computed. For such products as conventional lathes (0.83), milling machines (0.72), drill (0.75), DRC measured in terms of the existing exchange rate has been less than one: this analysis suggests that the industry is highly competitive.

From Ghulam Kibria: <u>A study of the machine-tool industry potential of indigeneous capability in the engineering industry of Pakistan</u>, National Development Finance Corporation Report No 21, March 1988.

difficulties to achieve export competitiveness often make their production commercially non-viable.

Machine-tool technological complexity can be measured through the ATC method developed by UNIDO. This method does not pertain to the product itself but to the technological requirements for its production.(3) The scoring is done by identifying and evaluating all the technologies involved in the entire chain of manufacturing processes leading to a finished product.

The global technological complexity index takes into account 103 sub-technologies or production factors. The score ranges from 16 for a primitive stove to 434 for a nuclear reactor and 563 for a twin-jet airplane. According to the survey which covers more than 1,100 capital goods, machine tools do not appear among the most complex capital goods to produce.

-The parallel precision lathe gets the highest score for machine tools, however it belongs to the same complexity group (scoring from 100 to 129.9) as motor cycles, television receivers and alarm clocks.
-Most machine tools can be found with the 213 product groups in the list which score form 40 to 69.9. This list includes radios, telephones, and bicycles. In descending order of complexity, machine-tools include rock drills, mechanical presses, circular saws, pneumatic drills, tubes and pipe benders, pneumatic hammers, staplers, blade sharpeners, and parallel lathes of the common type.

While product technological complexity does not appear to be a serious obstacle, the major technical constraints to entry are:

-availability of skilled personnel. The machine-tool industry requires engineers and workers specialized and having acquired some experience in metal-working industries. Such highly qualified workers are not easily found and are seldom attracted by a cyclical industry where layoffs may happen during the downturns. The advent of CNC machine tools and Computer-Aided Design helps to alleviate this skill constraint. However a sound knowledge of metalcutting technology is a prerequisite for deriving the maximum

(3) See UNIDO: Industry and Development, Global report 1989/90 Vienna, pages 122-131.

productivity from the use of CNC technology.
-existence of supporting industries in terms of castings, gear cutting, heat treatment for raw materials, components and technical services. The setting up of an integrated unit is a costly way to circumvent this limit.

1.1.2 Economic constraints

The shallowness and narrowness of domestic markets limits industrialization in all aspects but the potential capital goods producer is more severely hampered because he is twice removed from the final consumer: *"It is always easier to find 100 consumers willing to buy bicycles than to find 10 bicycle manufacturers seeking a machine-tool producer"*.[4]

The dimension of the market for machine tools is directly related to the state of development of the engineering industries (see Figure 17, Chapter 2). In most middle-income developing countries sales of machine tools are less than US$100 million a year, while in less developed countries they are often inferior to US$1 million. This market is also highly segmented :

-among user industries: in those developing countries where there exists a motor vehicle industry, this is usually the largest potential user, however its needs are mainly for special machine tools such as transfer lines. Elsewhere, bicycle and rural transport equipment manufacturers together with maintenance shops are the largest users.
-accuracy exigencies: users do not require the same measure of accuracy for their equipment. In the case of Pakistan[5] it has been estimated that 43 per cent of the market is for machines with tolerance limits up to 0.015 inch (0.375 mm), 30 per cent for machines with tolerance between 0.005 (0.125 mm) and 0.015 inch, 23 per cent for machines with tolerance from 0.001 inch (0.025 mm) to 0.005 inch and only 9 per cent for machines more accurate.

The cyclical nature of the market is another characteristic explaining the reluctance of entrepreneurs to enter the industry.

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(4) UNIDO, Industry and Development Global Report, 1988/89.
(5) See G. Kibria Box 17.

Market size constraint limits the opportunity of entry to those countries which are characterized by a minimum engineering industries value-added which could be estimated[6] at around US$100 million (1986). However, by placing too much emphasis on the constraints of the domestic market, one may fail to take into consideration the opportunities opened by regional and international markets.

-Regional market: Regional cooperation is a way to circumvent the market size limit: Arab countries market is estimated at US$150 millions, and that for the ASEAN countries is US$ 350 millions. (Box 18). The agreement between Argentina and Brazil in the capital goods sector has already provided a favorable environment for South-South co-operation in the machine-tool industry and could lead to joint common projects[7] as in the case of the agreement between Morocco and Tunisia.[8]

-The trend towards NC machine tools in industrialized countries offer additional export opportunities to developing countries in certain niche markets for conventional machine tools thereby generating new possibilities for South-South and South-North trade.

Even when the constraints of market size can be circumvented, one should not forget that entry is only feasible for those countries where there exists sufficiently developed engineering industries able to provide raw materials (such as castings) and offer subcontracting possibilities.

However, as noted earlier,[9] a large domestic market offers only static efficiency. In some countries, a large market can result in a disadvantage since it could undermine the dynamism of the industry. The quality of the home demand for machine tools appears to be equally important. It contributes to creating

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(6) This limit should be understood as a very rough approximation derived from statistical data only.

(7) R. Tauile, J. Erber: Machine tools in Latin America, UNIDO September 1990.

(8) A. Chelbi and A. Belhadj: L'industrie de la Machine outil en Algerie et en Tunisie, UNIDO 1991. There is a tripartite arrangement between the two countries and C-3M from France for the joint production of wood working and metal working machine tools.

(9) See Chapter 1 Par 3.5.

Box 18: From South-South to global demand

In the 1960s Taiwan took advantage of exporting to compensate for its small domestic market. Most exports went to South East Asia. As the market expanded. opportunities increased for raising new capital to achieve standardization and high quality. The transition from catering for a low income market to a high income market was less difficult than anticipated and the dynamism of South-South trade provided Taiwan machine tool producers with sufficient technical experience and capital to meet global demand: exports to the United States of America commenced in 1974 and they represented 54 per cent of machine tool exports in 1986. After the voluntary export agreement imposed in 1987, the share of exports to the United States has been reduced (26 per cent) while new markets were found in Europe (24 per cent); exports to developing countries represented 28 per cent in 1988.

From A. Amsden: "The division of labour is limited by the rate of growth of the market: the Taiwan machine tool industry", Cambridge Journal of Economics, 1985, pages 271-286.

dynamic efficiency when sophisticated domestic users put pressure on producers so that they upgrade their product lines.

1.1.3 Product mix and integration

New entrants into the industry tend to produce universal machine tools. Among the machines most frequently produced are drilling and lathe machines. Only a very small number of developing countries produce special purpose machine tools and numerical control machine tools.

In general[10] the product mix tends to be less specialized and this makes the task of production management more difficult. Moreover, in many cases, the initial lack of supporting industries (for castings, forgings) has justified the setting up of integrated machine tool industries and in many developing countries the level of integration is much higher than in industrialized countries. This choice which was justified when launching the industry, has led to high costs for some of the inputs due to the low utilization level of the supporting units within the firm.

In most developing countries conventional machine tools will remain the most widely demanded machine tools in the foreseeable future. In the case of Arab countries it has been estimated that the demand for NC machine tools will increase at an average rate of ten per cent per year between 1990 and 2000, more than twice the expected rate (4 per cent) for conventional machine tools: however, by year 2000, it has been estimated that NC machine tools would represent only 7.5 per cent of installed capacity.[11] Within industrialized countries (where still nine out of ten machines are conventional), manufacturers are shifting to the production of NC machine tools. Thus the entry into conventional machine tool manufacturing makes economic sense and it is also the only technological route towards the manufacture of more advanced equipment.

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(10) See M.M. Huq and C.C. Prendergast Machine tool production in developing countries, Edinburgh Scottish Academic Press, 1983.

(11) From Arab Industrial Development Organization: The development of machine-tool industry in Arab countries 1987 in: Le secteur de la machine outil en Algerie et Tunisie par A. Chelbi, ONUDI 1991.

Decisions concerning the product mix and the degree of integration should take into consideration the following:

-Self sufficiency is neither advisable nor possible. Countries should concentrate on a certain class or type of machine which offer higher plant utilization taking into account the dimension of their market and export possibilities. Developing countries have usually begun with simple machines such as universal lathes, small drilling and grinding machines -used in small domestic workshops and repair shops, the production of which is relatively easy. A 1974 UNIDO study categorized the capabilities of manufacturers into four levels of industrial development: limited, moderate, substantial and high. For each of these levels the different types of machine to be produced by developing countries moving into the industry were identified. (Table 44)

-In order to cope with the unreliability of sub-contracting services, developing countries have often opted for a high level of integration which has often resulted in very low levels of plant utilization. The difficulty to reach a proper balance between integration and subcontracting stems from the fact that the machine tool industry demand in terms of foundry, forging, gear making etc. is very small compared to similar demand from other engineering activities such as the motor vehicle industry: it is thus not feasible to promote a subcontracting industry geared to the needs of the machine tool sector alone.

The level of integration is one of the reasons of the large differences in capital intensity between countries in this industry, which cannot be considered as capital intensive. In Pakistan, on the basis of data from 188 units, the investment per worker was estimated at US$1500 while it was US$13,000 in the two integrated state enterprises.(12) In the Republic of Korea, where the industry is more sophisticated and more concentrated, capital assets per worker, were US$47,000 in 1986 as compared with an average of US$38,000 (1986) for the

(12) In A Study of the machine-tool industry, 1988.

Table 44: Machine-tool manufacturer's capabilities and scope of production

limited	moderate	substantial	high
bench drills	Engine lathes	Turret lathes	Gear grinding machines
bench grinders	Simple Milling	Automatic lathes	Special Purpose machines
sheet metal	Bench and Pillar	Bar and chuck type	Transfer machines
forming machines	Drilling Machines	Tracer Lathes	NC drilling machines
	Surface grinding	Precision grinding	NC boring machines
	Tool and cutter	Horizontal boring	Electro chemical milling
	drilling machines	Jig boring	
	Shaping machines	Gear Hobbing	
	Small Mechanical	Broaching machines	
	presses and brakes	Radial drilling	
		Screwing machines	
		Hydraulic and	
		mechanical presses	

Source: United Nations, The Machine-tool Industry, 1974 page 21.

manufacturing industry.[13] In India, capital investment in the Hindustan Machine Tool Plant has been estimated at US$350 million (27000 workers)[14] and in Algeria, fixed investment in PMO, a highly integrated unit which employs 500 workers was US$600 millions (1976).[15]

Integration within the firm may prove to be an alternative to plant integration. The machine-tool market is considered as a business where entrepreneurs cannot make money every year and to alleviate this constraint, machine tool production has often been started as a diversification from another metal working activity such as agricultural machinery.

1.1.4 Acquisition of technology

If one looks back at the history of the machine-tool industry, the main channel of technology transfer has been "reverse engineering" which is the respectable term for copying while transfer of technology through licences has played a far smaller role.

Reverse engineering has the following merits: low cost, new product development without technological dependency, indigenously accumulated capability and the possibility of developing appropriate technology. The American machine-tool industry acquired its technology through copying in the 19th century; in Japan, after the Meiji Revolution, the three sources of production were the arsenal, the repair shops and the craftsmen who copied imported machines spending several months making replicas.[16] This non formal channel has been widely used by other East Asian countries. (Box 19)

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(13) UNIDO: Industry and Development, global report 1989/90, Vienna, page 104.

(14) Hyung Sup Choi: Hybrid of man and technology, Asian Productivity Organization, Tokyo 1989, page 147.

(15) A. Chelbi and A Belhadj: L'industrie de la machine outil en Algerie et en Tunisie, UNIDO 1991.

(16) Toshiaki Chokki: A History of the Machine-tool industry in Japan in Fransman.

Box 19: Example of reverse engineering

Firm A started developing a belt-type lathe after scouting out for an experienced engineer to imitate the locally-available Japanese-made lathe. They copied the lathe successfully by reverse engineering without drawing. The engineer played a key role in the successful duplication of the belt type lathe. Exchange of technical personnel resulted in human technology transfer. Although the precision of the lathe was very low, lathes made in Firm A maintained their lead position until the mid-seventies.

Firm A started to use drawings in their production process development in 1964 when the gear type lathe was developed through informally acquired drawings as well as a Japanese model. Later Firm A utilized drawings in the development of the NC lathe; it succeeded in this development via commissioned research with a domestic technology institute after one year.

Technological development pattern of firm A

	Product	Development year	Development period (month)	Development method
copy without drawing	belt type lathe	1960	3	Sccut domestic engineer and copy well known lathe
imitation with drawing	gear type lathe	1964	12	Procure drawing and imitate
	engine lat	1967	6	purchase a lathe and imitate
	high speed	1976	6	copy
	gear type milling	1976	6	Imitate Japanese machine
Development of new product through	NC lathe *	1977	20	Joint development with domestic institute
	grinding machine	1980	6	Contract to introduce drawing
	NC milling	1983	12	Indigenous development
	Copy milii	1983	12	Indigenous development
	Machining	1983	12	Development from the basic design

* Electronic parts imported from Japan

Source: Zong-Tae Bae and Jinjo-Lee: Technology development pattern of small and medium sized companies in the Korean Machinery industry in Technovation 4(1986) 279-296.

A survey[17] of nine machine-tool builders in Taiwan, Province of China has shown that almost all machine-tool companies whether large or small, acquired their initial know-how through copying or reverse engineering. The products of the competing firms (domestic or foreign builder) provided an important design input and appeared to be the most important sources of improvement. Local firms applied the "learning by using" interaction between producer and user. Copying has its limitations. Without access to the blueprints it is harder to introduce design modifications either in the machine tool (by reducing the number of gears in a design) or in its use (by simplifying the set-up). Nevertheless evidence from Taiwan, Province of China shows that the best companies have not merely copied foreign models but have modified and improved them over the years. Product improvements include better control, magnetic relays, and modification of the air cooling system and have also served to raise productivity on the shopfloor.

The usual way to enter the machine-tool industry is through a backward progression from sales to servicing and then to licence for assembly of knock-down kits and further to full manufacture.[18]

There are several forms of licence arrangements:

-license for the assembly of kits of existing, and frequently outdated models. This has very limited technology transfer;
-license for the manufacturing and assembly of machine tools of existing designs in country of licensee or for sales in export markets;
-joint venture agreement with full technology transfer and design development content.

For setting-up of conventional machine tools a wide range of possible suppliers of technology exists, and several developing countries have engaged in cross licensing.

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(17) See A.H. Amsden, 1985.
(18) UNIDO: Technological requirements for the machine-tool industry in developing countries, UNIDO, IS.462, June 1986.

Opportunities for South-South cooperation(19) also exist while the trend towards internationalization of machine tool builders offers additional possibilities.

1.1.5 Industrial policy

As discussed in Chapter I, governmental policy is important in shaping the four determinants of a national industry competitive advantage. Industrial policy has played a significant role for the development of the machine-tool industry in several industrialized countries: fiscal incentives, local protection from imports, procurement policy are among the main policy measures.

As any other infant industry, the newly established machine-tool industry is vulnerable and requires some form of protection during the learning period. A counter example is provided by Mexico where the low protection given to the capital goods industry has inhibited the local production of machine tools. It is important that the industry should become economically viable as soon as possible because prolonged protection which may lead to inefficiency within the industry, will be injurious to the successful development of the country's engineering industries as a whole. As seen in the case of the Republic of Korea (Box 20), the machine-tool industry can be both protected from foreign competition and competitive on the international markets.

The procurement needs of the State concern primarily the demand of state owned enterprises and the demand from educational institutes.

Government may also play a role as a mediator between the often conflicting interests of users, looking for the best equipment available, and of producers endeavoring to upgrade their production. In doing so the Government should ensure a close technological collaboration between users and producers in product development in order to ensure that machine-tool

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(19) Such opportunities were drawn to the attention of the UNIDO Working Group on Cooperation on Production and Application of Machine Tools among Selected Developing Countries, Shanghai, May 1989.

Box 20: <u>Protection and competitiveness</u>

In the Republic of Korea the Government introduced several plans dealing specifically with machine tools. Two major instru. ents have been used.

-Total prohibition of imports where similar locally-produced tools were available. The Korean Machine Tool Manufacturer's Association was empowered to decide whether similar domestic goods were obtainable and whether i..oorts should be restricted, an arrangement that has drawn criticism from within the country.
-Granting of subsidized credit to machine tool-producing firms

An important feature of these instruments were that the benefits which they provided were made contingent on export performance. This forced firms to confront the issue of international competitiveness even while enjoying subsidized credit and protected conditions on the domestic market.

From Fransmann: <u>Machinery and economic development</u> and P. Judet: <u>L'industrie de la machine outil en Coree</u>, UNIDO 1990.

Table 45: <u>Numerical Control Machine-tool production in newly industrialized countries</u>

	1985		1987		1988		1989		Share of NCMT
	US$ mi.	units	US$ mi.	units	US$ mi.	units	US$ mi.	units	in production value of Machine Tool
Argentina	1.20	16	10	100	12	96			20%
Brazil		413	223	1018	226	742		1052	43%
India		93		330	71	312			26%
PR China						1000*			
Republic of Korea	38		134	2039	155	2119	250		27%
Taiwan Prov.China	42	1118	114		166	3600		4900	24%

<u>Sources</u>: CECIMO
Brazil Bolletim Sobracon 1989
Electronics Korea February 1990
* Output of mechanical portion of CNC machine tools

producers meet the technological requirements of users. The establishment of state funded research and development institutes to assist producers and users has been an important incentive for the development of machine-tool industry in several countries.

1.2 Entry into numerical control machine-tool production

A few developing countries have entered into the production of NC machine tools (NCMT) and their experience indicates that electronics technology, per se, is not the principal constraint.

1.2.1 Developments in the newly industrialized countries

Table 45 provides the available statistics on the production of NCMT in some newly industrialized countries. The share of NCMT in total production value for machine tools in these countries lags behind that of most industrialized countries (around 60 to 70 per cent). The transition to NC machine tool manufacturing is however rapidly underway in these countries, with NCMT accounting for on average 25 per cent of production in value (30 per cent for metalcutting machine tools). The NCMT production volume is comparable in terms of units to some European countries,[20] but lags far behind that of Japan (which produced 48,000 NCMT in 1988). However, the NCMT ratios in production are sometimes strongly influenced by the high price of NCMT; this is specially the case in Brazil where NCMTs accounted for 3 per cent of production in volume (compared to 30 per cent in industrialized countries).

Production of NCMT has concentrated on lathes and machining centres which represent 74 and 78 per cent respectively of the total number of NC machine tools produced in Brazil and Argentina. In Taiwan, Province of China there is a trend towards diversification to NC drilling and NC boring machines, electro discharge machines and flexible manufacturing cells.[21]

1.2.2 Mastering of technology

The experience of the New Industrialized countries suggests that the competent machine builders have not encountered many difficulties in assimilating the new product technology.

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(20) NC production in France: 2,900 units in 1987, in the United Kingdom 2

(21) In 1984 a Taiwanese company exported the first FMS, American Machinist, February 1984.

A survey of several machine tool builders in Taiwan, Province of China concluded[22] that "*none of the sample firms reported serious difficulties in the introduction of CNC products... and none of them foresaw major difficulties in upgrading product quality over time in order to keep up with Japanese progression*". Only the strongest firms were able to make the change to CNC entirely in-house while most of the others were provided technical assistance by the supplier of CNC controls. A survey made in the Republic of Korea (Box 21) has pointed out that the main difficulty laid in that country more in the mechanical parts (servo motor, measuring devices, cutting tools, spindle and hydraulic components) than in the electronic or software field.

These examples underline the obvious, but often ignored point, that: "*the export aspirations of developing countries in the machinery sectors are constrained on the technical side not by their lack of information technology skills but because of the pervasive weakness in their basic mechanical engineering and machine design and building capacities.*[23] If those countries can overcome these obstacles to the point where the export of conventional machines is a viable proposition, then experience suggests that moving into the microelectronics era will not be as great a hurdle for many developing countries willing to invest in system integration and programming skills development.

1.2.3 Local integration

The high bought-in content in NC machine tool manufacturing differs from conventional machine tool manufacturing. (Table 46) While the cost of materials represents 40 per cent of the cost of an engine lathe, bought-in material accounts for 75% of the production cost of a CNC lathe. There is also a difference in the type of bought-in material: raw material (castings) account for 25% for conventional while only 12% in CNC. The control system's share may be 25 to 40 per cent of the total

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(22) M. Fransman: "International competitiveness, technical change and the State: the machine-tool industry in Taiwan and Japan". World Development vol.14 No. 12 pp 1375-1396, 1986.

(23) K. Hoffman: "Technological advance and organizational innovation in the engineering industry", Industry and Energy Department working paper, Industry series paper No. 4, The World Bank, March 1989.

Box 21: Identification of the main technical constraints encountered by Numerical Control Machine Tool Manufacturers

		Lag with industrialized countries (in years)	Acquiring the Technology
Hardware	electronic equipment		
	Central Processing unit	3 to 5	local development
	Monitor and key board	3 to 5	import
	Programmable controller	1 to 3	local
	electrical and mechanical		
	transformer	5 to 10	local development
	servomotor	more than 10	import
	measuring device	more than 10	import
Software	for the tools		
	motor	1 to 3	local development
	multiple axes controler	1 to 3	local development
	for the peripherals		
	control of sequences	1 to 3	local development
	interface	3 to 5	local development
	specific software		
	graphics	1 to 3	local development
	numerical control	3 to 5	local development
Technical conception			
	main types of machines		
	machining centres	1 to 3	local development
	lathe	1 to 3	local development
	milling	3 to 5	local development
	EDM	5 to 10	import
	mechanical components		
	cutting tools	more than 10	local development
	spindle	more than 10	import
	transfert system	3 to 5	local development
	hydraulic components	more than 10	import
Manufacturing and assembly technology			
	main operations		
	die casting	5 to 10	import
	thermal treatment	5 to 10	import
	finishing	1 to 3	local development
	quality control	1 to 3	local development
	automation		
	conception and design	5 to 10	import
	production	1 to 3	local development

Source: Korea Institute for Economics and Technology 1988, in Judet P.: L'industrie de la Machine Outil en Coree, ONUDI, 1990.

Table 46: Basic manufacturing characteristics of conventional and CNC machine tool

feature	Conventional machine tool	CNC machine tool
material and labour	intensive, predominantly - cast iron structures - dependent on gear drives - constant speed drive motors	Specialized content consists of 50 per cent of the work cost and comprises electric, drives, computer which are usually bought from several suppliers
Structure	Comprises 80 per cent of work cost	DC or AC drives. Little or no gearbox Structure account for 50 per cent of the work cost
Manufactured contents	Large. All parts made in house including castings and all machining including many gears	Small. All Components parts may be subcontracted except for the finish machining
Management structure	Classical. People oriented Works manager is totally accountable for production	Project management structure equipment oriented: the electrical buyer carries similar responsibility as the as the works manager for production

Source: UNIDO Technological requirements for the machine-tool industry in developing countries, IS/642, 1986.

costs of a CNC machine.

The local integration of the core parts of NC machines is a difficult task. The stagnation of the rate of localization for NC machine tools in the Republic of Korea since 1985 illustrates the difficulties encountered. (Table 47)

Local production of Numerical control units has begun in Brazil and in the Republic of Korea where the domestic markets are respectively US$20 million and US$ 55 million.[24] In Brazil the production is segmented among three captive suppliers (machine tool producers) and four "merchant suppliers" which cater for different markets (80 per cent of the market). Competition is minimal although this monopoly has been challenged by an electronic firm which developed a simple model of NC. Box 22 discusses possible technological routes from the manufacturing of conventional machine tools to entry into production of Numerical control machine tools which gives the emphasis on software.

1.2.4 Price competitiveness

The success of exports of low cost stand alone NC machine tools and machining centres by East Asian producers[25] is the first evidence of the competitiveness of the machine-tool industries of these countries. Comparison between East Asian and Latin American NC machines tool prices offers evidence of high price differentials. While comparison of unit prices for similar machines (and average prices) between Japan, Korea and Taiwan, Province of China shows a small differential, Table 48 shows a large price differential between East Asian, India and Brazil where the average domestic price of a NC machine tool is five times the Korean average price. South Korean machining centres are also between a half and a third of the Argentinian prices.[26]

The high price of these machines is hampering the modernization of the industry in Latin America. During an unstable economic period decision makers are not inclined to take

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(24) Electronics Korea, September 1989.
(25) For instance: the Voluntary Export limit agreement imposed on Taiwan, Province of China.
(26) Chudnowski and Groisman, 1987.

Table 47: Localization rate in the Republic of Korea

in percent

	1980	1985	1989
conventional lathe	85	95	95
milling	80	88	
grinding	70	90	
NC machine tools			
NC lathes	20	44	47
machining center		52	52.50
EDM			10.80

Source: Korean Institute of Economics and Technology

Table 48: Price comparisons of machine tools.

	Japan (1)	Republic of Korea (1)	Taiwan,China (1)	India	Brazil (3)	Mexico (4)
conventional lathe	7.50	5.80	5.10			
NC lathe	69	53	46			10 to 30
Machining center (1250x400 mm)	74	59	52			12 to 50
average NC machine tool domestic price (2) :	102	79	47	164	300	

Sources: (1) Korea Machine tool Manufacturer Association in May 1989
(2) CECIMO
(3) Boletim Sobracon 1989
(4) Import price range in 1990

Table 49: Inputs for the machine-tool sector in Brazil
(ratio between domestic and international prices)

Steel and plates	.94
Ferrous castings	1.32
Non ferrous materials	.30
Electrical engines	.52
Electrical components	1.71
Electronics components	2.77
Hydraulic components	1.81
Ball bearing	2.95
Forged parts	1.22

Box 22: Choosing a technology transfer route to develop CNC technology

There are three possible routes which can be followed to transfer and/or develop CNC technologies:
(i) purchase the complete package through a turnkey operation from an internationally known owner supplier
(ii) to unpack the technology package and indigenously develop everything from scratch
(iii) to adopt a mixture of (i) and (ii), that is while sub contracting some parts of the technology package to foreign companies with experience in the respective areas, to develop the remainder indigenously.

The selection process of the appropriate route is a function among others of: availability of technology, costs involved, time required to assimilate the technology, manpower requirements, risks involved in reaching the set targets and depth of assimilation of technologies.

While state-of-the-art microprocessor based CNC systems are moving towards the 32-bit complexity; 16-bit CNC system technology is available: they are still being manufactured and marketed by all major companies. Turn key operation is the fastest method of technology transfer, and indigenous development, which requires a large number of skills, takes the longest time. However when these two routes are compared in terms of deepness of assimilation of technology, the indigenous development looks preferable.

	Technology transfer route		
Parameters	Turn Key	Indigenous	Mixed
Difficulty of obtaining of technology	*	****	***
Costs involved	****	*	**
Manpower requirements	*	****	***
Chances of not reaching set targets	*	***	**
Time required to assimilate of technology	**	****	***
Chances of failing to assimilate technology	****	*	**

**** very high
*** high
** medium
* low

Adapted from CNC system development, Project document DP/CPR/89/017/A/01/37 risks, and this includes investing in modernization. Most car component firms in Brazil set a two-year pay-back period in their acquisition of new equipment[27] and this makes the acquisition of NC machines not feasible.

A substantial portion of the high cost of NCMT in Brazil can be attributed to the domestic cost of inputs supplied locally as compared to import prices (Table 49); Brazil's market reserve policy[28] has contributed to the higher prices of electronics equipment . The low level of production is another explanation. While the production of conventional lathes was associated with low requirements of technical efforts in the design sphere and the absence of economies of scale, for CNC lathes the opposite is true.[29] Specialization is necessary not only to master a rapidly evolving and complex technique but also to reap the benefit of dynamic scale economies in the form of learning and of static economies of scale both for the acquisition of components (due to the high ratio of bought in component) and in marketing. In Brazil interviews with local producers have confirmed this situation.[30]

This suggests that the entry into NC machine-tool production should be made in a very selective way, with increase in specialization instead of diversification. It follows that protection should also be devised in a very selective manner, aimed at specific segments of the industry and even firm specific.

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(27) R.R. Lima: "Implementing the Just-in-Time production system in the Brazilian car component industry", IDS Bulletin 1989 vol 20 No. 4 1989 page-14-18.

(28) Under this policy Brazilian produced equipment prices are between three to five times higher than in the international market place and after more than four years of market protection this difference seems to be increasing rather than declining.

(29) S. Jacobsson: "Intraindustry specialization and development models for the capital goods sector", Weltwirtshaftliches Archiv Bd CXXIV 1987.

(30) In F.S. Erber, UNIDO 1989.

2 Impact of technological changes on engineering industries in developing countries

There is widespread evidence that the rules of competition are rapidly changing in the world manufacturing market and this evolution will have an important impact on the developing countries. Products characteristics and product innovation have become the primary determinants of competitiveness. This is particularly true in engineering industries where shorter life cycles and greater flexibility in response to customer's needs play a larger role. Flexible manufacturing practice is becoming the best manufacturing system in mass production industries like automobiles or in such craft activities as machine tools. Numerical Control Machine Tools on the shopfloor, Computer Aided Design workstations in the design department are examples of individual automation technologies on a stand-alone basis which are slowly integrated into island automation and flexible manufacturing systems. There is an important trend towards more product diversification and more competition in design, distribution and services in addition to actual production.

What will be the consequences for developing countries? A number of analyses have argued that flexible automation technologies will emphasize the comparative advantage of industrialized countries. In this view the application of computers to production could serve to draw manufacturing back to the North. It has been argued(31) that: *"The industries in which the United States can retain a competitive edge will be based not on huge volume and standardization, but on producing relatively small batches of more specialized, higher-valued products. Such products will be found in high-value segments of more traditional industries (specially steel and chemicals, computer controlled machine tools, advanced automobile components) as well as in new high-technology industries (semi-conductors, fiber optics, lasers, biotechnology and robotics)".*

While most observers agree that the strategy to adopt to compete in the international market can no longer be based on low wages, high labour content, there are conflicting views on the impact of these changes. Will they offer new opportunities of production for those countries whose domestic markets are too small? Will they slow the move towards international production?

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(31) R. Reich: The Next American Frontier, New York Times Books 1983 page 130.

2.1 General assessment

It is widely believed that the present technological revolution will leave most developing countries in a somewhat worse position than in the past: flexible automation will allow industrialized countries to increase their competitiveness in manufacturing.

2.1.1 Threats

While the developing countries as a whole managed to continue to attract international direct investment over the period 1975-79, since the beginning of the 1980s private resource flows to these countries have fallen off sharply despite the fact that they have adopted a more favorable attitude to foreign investment. There has been a decline in foreign investment in Latin America and divestment in the case of Africa while investment in South East Asia has strongly picked up since 1986.

Technological change is one among many factors(32) explaining this recent evolution. In the future, as the direct manufacturing component of total cost declines, large firms will be increasingly disinclined to fragment their operation, with the accompanying penalties in terms of more complicated logistics, inventories controls and so on. The logic of the situation would seem to indicate a future trend toward the co-location of production with major markets. Flexible automation seems to reduce the benefits of extremely large scale production facilities and this in turn suggest a more dispersed decentralized production system with many more small plants located near markets, in industrialized countries or in developing countries.(33)

The competitive advantage of low wage countries may also be

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(32) In the case of Latin America, the decline in international direct investment is attributable to the heavy external debt which has had a major impact on the overall economic situation. In the case of Africa, the small scale of the local markets, the shortage of trained personnel, the lack of infrastructures. flat demand for commodities and the increased indebtness. See OECD: Recent trends in international direct investment Second round table on foreign direct investment, Tokyo 1989.

(33) R.U. Ayres: Future Trends in Factory Automation, in Manufacturing Review vol 1, Number 2, June 1988.

diminished to the extent that by depending more on human labour than the industrialized countries they may find themselves unable to produce goods of the requisite international quality standards.

In Chapter II it has been shown that the diffusion of flexible automation techniques in industrialized countries has a great impact on engineering subsectors such as machine tools (Japan, France), engines and turbines (Japan), special industrial machinery (Japan, France), instrument and ordnance (United Kingdom). These product groups are predominantly produced under import substituting schemes in developing countries[(34)] and their export performance has been relatively poor due to the fact that they are technically complex.[(35)] Thus, in the future, those countries may be running up against new obstacles.

Impact is less significant in industries such as handtools, structural metal products, and motor vehicle parts: these product groups constitute a large share of the value of developing countries engineering production. They are on the whole technologically simple and some developing countries have had a good export performance. The uneven global diffusion of flexible automation techniques in these industries therefore does not constitute a significant threat.

In assessing the negative impact of flexible automation on the competitiveness, one should stress that cost reduction will mainly affect machining costs which in most cases represents 15 per cent of the engineering costs. The cost saving impact of the adoption of new organizational schemes by firms in industrialized countries may be far more important.

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(34) A point analyzed in the case of the Republic of Korea.
(35) However, as mentioned by Edquist and Jacobsonn, the possibility exists that flexible automation techniques have already had an impact on the international competitiveness of industrialized countries at the expense of the developing countries.

2.i.2 Opportunities[36]

The impact of flexible automation techniques would appear to be different depending on what the alternative to flexible automation is. If the alternative is manually operated, stand-alone machines such as engine lathes, the impact on the developing countries appears to be negative. However if the traditional alternative to flexible automation is fixed automation in the form of transfer lines, the picture alters significantly. Transfer lines are normally used for the production of long series of homogeneous products and are frequently used in the automobile industry. Fixed investment is high and large scale production is needed to justify this investment. Generally speaking, investments of this type are less justified in the developing countries than in the developed countries given the more limited market in the former.

The move towards flexible automation observed in the developed countries opens up very interesting alternatives for those developing countries that have a smaller local market. These countries now have the opportunity to start producing products, such as diesel engines, with flexible automation, and compete with imported products at much lower volumes of production than was possible if the technique used was transfer lines.

2.2 The case of automotive components

The world automotive industry is entering a decade of intense global competition and rivalry and a new phase of restructuring is underway with the focus on Europe. This global challenge is leading to the development of an exclusive group of so called first tier component suppliers which are becoming crucial to the vehicle makers' ability to maintain a technological lead. The move towards globalisation does not mean that components will be sourced from all the corners of the world:[37] the move towards just-in-time technology suggests that this is unlikely- but rather that multinational components producers will have global representation in terms of manufacturing plants.

The automotive industry has been traditionally seen as one of the most strategic and favored manufacturing sectors targeted

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(36) This paragraph draws from Edquist and Jacobsonn: Flexible automation 1988.

(37) Financial Times: "World automative components survey; Fewer and bigger groups", 16 May 1990.

for development in many developing countries. Some developing countries (for example Indonesia) actively pursued the local manufacture of motor vehicles as part of a broad industrial policy to foster the growth of metal and machine tool industries. It is based on the premise that local production of numerous parts and components would stimulate the development of those industries. The trend in world car components production will have an important impact on developing countries where the prospects for manufacturing their own cars may appear dim. Many components are traded world-wide and this sector offers opportunities for a South-South complementary scheme.(38)

In order to assess the evolution of firm policies towards the purchase and manufacture of components, a recent study (39) distinguished between five categories of components which are subject to processes of technological change in order to help determine which are the most likely to be purchased and which are likely to be manufactured in-house, given the general policies of each assembler as to appropriate make/buy mix which they adopt. This distinction provides some clues as to the role developing country producers might play.

2.2.1 Technology and trends in global sourcing

Generic components: These are components common to many industries i.e. nuts, bolts, screws, fasteners, etc. and which are used in multiple numbers in vehicles but comprise less than five percent of total component cost. In general this type of component tends to be physically small so that the transport cost -to-value ratio in production and distribution is low. Moreover, because their mass production allows the use of dedicated machinery, plant scale economies are high, production is specialized and often concentrated geographically, with output distributed on a wide, often global basis.

There is only limited evidence(40) that this category of components is undergoing significant change in product or

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(38) See UNIDO, Industry and Development Global Report 1989/90, pp.100-105.

(39) This part is taken from Hoffman and Kaplinsky : The driving force The global restructuring of technology,labour and investment in the automobile and components industries, Westview Press, 1988.

(40) See part II, the impact of diffusion of NCMT in Japan.

process technology, (such as flexible automation in screw production) but in the medium term they are likely to be substantially altered by changes in materials technology in automobile production itself. Most important here is the trend towards the use of plastics (which is self evident) where the ability to mould complex shapes means that single products can be substituted for groups of components which are currently often joined with generic industrial fasteners.

Bulky, non-mechanical parts. These include mufflers, glass, stampings, seats, fueltanks and radiators. Such parts are low in both product and process technology content. By their nature they are tailored to the specific characteristics of the product and, because they also tend to have a relatively high transport-to-value ratio, it is common to find these parts produced near the final market.

Individual components amongst this group are undergoing significant technological changes. In some cases these are occurring through changes in production processes. This is the case with products such as fueltanks and mufflers in which the introduction of electronic controls allows for rapid readjustment of machine-settings, and therefore facilitates the flexible automation of production.

In other cases there are important changes in design and in materials technology, such as in the introduction of plastic fueltanks and aluminum/copper radiators, or the development of molded seats.

Various items of trim and wiring. These components are traditionally characterized by low technology and low transport costs -they include wiring harnesses, window handles, switches, exterior trim, interior upholstery material as well as spark plugs, points and windscreen wipers. As both their technological content and their unit transport costs tend to be low, production of these components has historically been considered as an appropriate form of international specialization for low-wage economies.

Technological change is likely to have some impact on this category of components. In the case of wiring harnesses, the move towards centralized computer control and multiplex wiring in automobiles is likely to eradicate the need for this labour-intensive product. Similarly, the trend towards systems in window control -with centralized consoles and electrically operated windows- is likely to obviate the need for forged handles. Points have been rendered obsolete by electronic engine controls, and switches are becoming much more complex. Moreover, the introduction of electronically controlled flexible production systems is injecting scale economies into small batch production and making it considerably more complex and capital intensive in nature. It is possible that many of these types of component will be significantly affected by the introduction of electronically-controlled systems in products technology.

Electro-mechanical and systems components. This comprises items such as carburetors, clutches, starter motors, ignition systems, brakes, shock absorbers and steering mechanisms. Traditionally their relative technological complexity and low transport-to-value ratio has seen these components being produced in the industrially-advanced countries. However, as technological capability in some NICs has increased, so has production begun to be transferred to these areas.

It is here that a particularly acute impact of technological change on developing country sourcing may happen since three related factors are rapidly impinging on the organization of production.

-First the introduction of flexible manufacturing systems, together with improvements in assembly automation are transforming a labour-intensive industry into a capital-intensive one.

-The second type of technological change having an impact on this type of component is the modularization of production through the development of subsystems, generally electronically control. Thus by facilitating mechanization, by requiring systemic assembly and by being more technologically complex, the scope for sourcing in developing countries is likely to be substantially reduced by technological developments.

-Thirdly, the relationship between component-suppliers and assemblers will change and become much closer, especially at the design stage. To the extent that this occurs, the importance of this phenomenon is likely to become greater in the more technologically-complex items such as these.

2.2.2 Automation and the spreading of offshore production

Automobile production may require a fair amount of unskilled and semiskilled labor, but it also requires a considerable application of technology, production planning, and coordination that is not widely found in developing countries and could not easily be transplanted there. Low wages alone are not a sufficient attraction for moving abroad in a sophisticated industry. Both low unit costs- a combination of wages and productivity- and high quality are essential. However, if sophisticated production could successfully be located offshore, low wages would mean low unit costs.

The results of a comparative analysis[41] of similar engine plants located in Mexico and in the United States offer some interesting insights. The plants produce the same 4-cylinder engine, operate at comparable production volumes, utilize similar technologies in key departments and are managed by a single division of the same company. While the Mexican plant is a new one and produces only one type of engine, the American one contains a new engine line in a 27-year old plant and produces four types of engines. The analysis focused on two of the most critical transfer lines, the block and crank lines. Machining lines contain operations requiring greater precision and suffer much more downtime than assembly lines. Technological complexity and the cost of idle equipment place a premium on the experience and skill of the hourly work force.

One of the study's central finding is that the Mexican plant achieved comparable machine efficiency, labor productivity, and quality to the US plant within its first two and one-half year of operation. The Mexican plant had a young, inexperienced work force while the workers in the US plant were seasoned veterans. The company selected highly-motivated and well-educated work force and provided intensive training. Central to the plant's success was the form of organization that seemed to evolve. A high level of knowledge and experience is necessary to operate an automated factory and these attributes are only gained in years. As the Mexican plant shows, this skill does not have to be evenly spread throughout the organization. For its launch the plant had sizable numbers of experienced managers drawn from the company's operations around the world which made diagnostic decision that skilled workers would normally make in a North American plant while the Mexican work force would carry out these directives. The plant has brought high technology and training in Mexico, it may serve largely as an island of high technology or if it

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(41) H. Shaiken, S. Herzenberg: Automation and global production, automobile engine production in Mexico, the United States and Canada Centre for US-Mexican Studies, University of California, San Diego, Monograph Series, 1987.

develops local source of supply it could serve as a catalyst to diffuse advanced techniques more widely.

The findings of this study go beyond the automobile industry. The ability to produce automobile engines offshore indicates an ability to manufacture other products as well. As industrialized countries continue to automate, offshore production may rise instead of fall.

3 Industrial automation in developing countries

The process of diffusion of flexible automation among industrialized countries progressed unevenly in the early 1980s. However this technology has now spread widely and it will have significant effects on competitiveness and employment in the years to come. Some of the factors which have contributed to this evolution are not relevant in most developing countries (i.e. the reduction of labour costs[(42)] or the pressure for more customized products.[(43)] However, the increase in competitiveness in the industrialized countries might inevitably force developing countries to follow suit in order to either penetrate export markets or compete with imports.[(44)] Investing in flexible automation may contribute to building dynamic comparative advantages.

After an assessment of the rate of diffusion of industrial automation in developing countries, guidelines

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(42) With the noticeable exception of East Asian countries (mainly Singapore, the Republic of Korea and Taiwan, Province of China) where shortage of manpower and/or wage increases have accelerated the move towards industrial automation.

(43) It is often assumed that as income rise consumers can express in the market more refined wants for more specialized goods; in this view mass markets are a consequence of low standard of living. However, as pointed out by Piore and Sabel (1983), this distinction between the needs of the poor and the wants of the rich flies in the face of massive ethnographic evidence which show that at every leve of consumption the desire for particular goods is shaped by collective, cultural ideas of what is right and what is beautiful.

(44) Due to import liberalization measures taken in a growing number of countries, local engineering firms are now exposed to foreign competition.

Box 23: Difficulties in importing NC technology

An Asian Productivity survey among machine tool manufacturers in Taiwan, Province of China has identified the following difficulties in importing NC machine tools:

-Managers lack knowledge on new technologies: most of them learned technologies as apprentices and do not understand new technologies very well and therefore are not interested in introducing them unless the existence of the company is threatened.
-Resistance of the workers because of the changes introduced in the organizational structure
-High risk since the return on the large investment made may be uncertain and long term

The results fall often short of expectations:

-Managers do not give the introduction of new technologies careful consideration
-Low skilled workers cannot adapt to the new technology even through education and poor working environment and salary cannot attract advanced technical personnel
-Household-type management cannot meet the requirements of new technologies.

From: Hyung Sup Choi (Edit): Hybrid of Man and Technology Asian Productivity Organization, Tokyo 1989.

concerning the choice of technology will be discussed together with the prerequisites in terms of organization.

3.1 Diffusion of numerical control machine tools in developing countries

The diffusion of NCMT among developing countries has been by and large, concentrated in those countries which are significant machine tool builders with only scant evidence of their diffusion in other countries. Inventories of machine tools seldom exist and data concerning the diffusion of NCMT by engineering industries sub-sectors are not available. In some cases the introduction of automated equipment is due to the initiative of foreign enterprises which have convinced their subcontractors to adopt flexible automation in order to export quality products.(45)

3.1.1 Newly Industrialized countries (Table 50)

The diffusion of NCMT has increased at a very fast pace in the newly industrialized countries of Asia where firms have invested in order to maintain their export competitiveness. A tight labour market, the increase in salaries (100 per cent in dollar terms from 1986 to 1989) and the revaluation of currencies have prompted the move towards automation.

- In 1985 the Republic of Korea had 2680 units installed; this number more than doubled in the subsequent three years to reach 6500 in 1988.
- In Taiwan, Province of China the number of NC units was estimated at 6200 in 1988.
- In Singapore, automation is a priority(46) and a National Master Plan has been launched: there were 1800 NC machines in use and 380 robots(47) in 1989.
- In India, the census of machine tools of 1982 has shown that there were 1182 NCMT installed; three sectors accounted

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(45) Several examples can be found in the case of automotive components in Latin America or in South East Asia (Malaysia and Thailand).

(46) Ministry of Trade and Industry: Economic Survey of Singapore 1989, page 25.

(47) Most of them are used for assembly operations and 57 per cent are employed in the electronics and electrical industries.

Table 50: Stock of NCMT in selected developing countries

In Units	1981	1985	1987	1989
Republic of Korea		2680	5000	7500
Taiwan Prov.China		1220	2800	6250
Brazil	986	1995	4176	5800
Singapore	60	700		1800
Mexico				1300
Argentina	350	500		800
Colombia			61	
India			1182	

Sources: Case studies by F. Erber and M. Humbert
and estimates from production and trade figures
Singapore: EDB, Economic Survey 1989.

for over 70 per cent of the machines installed: machinery and parts, transportation and electrical machinery. For 1986 and onwards documented data is not available, however a sample survey among twenty five large enterprises indicated that the percentage of flexible automation in the investment in machine tools has increased very significantly from 25 per cent in 1985 to 41.7 per cent in 1989.(48)

-The number of NC machines per thousand employees is around 6.5 in the Republic of Korea, 15 in Taiwan, China and 27 in Singapore as compared to 20 per thousand employees in the US engineering industries

The economic recession has slowed down the pace of industrial modernization in Latin America. In Argentina there were 350 NCMTs in 1981 and 800 in 1988; the initial wave of acquisition took place when wages were relatively high and import of capital relatively cheap due to the overvaluation of the peso; it continued in a situation of relatively low wages and the introduction of NCMT was linked to a process of expansion into more complex products.The use of flexible automation is sometimes associated with a systematic effort to enter foreign markets: this is the case in Argentina (49) and in Brazil,(50) however in Colombia the companies presenting the largest volume of exports were not those using NCMTs.(51) The machine tool, automobile and aircraft industries account for the largest number of NCMT in Brazil: quality considerations and complexity of the parts produced and the strict margin of tolerance seem to represent the majors reasons for the introduction of NCMTs in Argentina and Brazil.(52)

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(48) H.C. Gandhi: Regional study on machine-tool industry in Asia, the Case of India, UNIDO 1991.

(49) D. Chudnovski: The diffusion and Production of Numerically controlled machine tools with Special reference to Argentina, World Development, vol 16 No 6 pp 723-732, 1988.

(50) A survey of autoparts manufacturers conducted in 1984 has shown that the manufacturers which used NCMT were those presenting the highest export ratio R.Tauile: Automacao e competitividade, uma avaliacao das tendencias no Brasil Instituto de Economias Industrial, Rio de Janeiro, 1987.

(51) Fedemetal: Las nuevas technologias de base microelectronica: analisis global e impactos de su incorporacion al sector metalmecanico de Colombia, Bogota, 1988.

(52) R. Tauile, F. E. Erber: Machine tools in Latin America UNIDO, 1990.

-In Brazil the installed capacity of NC machines increased from 986 in 1981, 1995 in 1985 and 5970 in 1989; they are concentrated in a rather small number of companies: 420 in 1987 which are both large corporations (above 500 employees) and subsidiaries to foreign companies. According to a study by the Research and Technology Institute of the University of Sao Paulo, although a few well-known machine tool makers produce advanced equipment, the average age of machinery is 15 years(53)

-In Argentina the stock of NCMT increased from 350 (1981) to 800 units (1989). The diffusion of NCMT has included small and medium enterprises from the outset, probably because both locally produced and imported models were simpler and less expensive(54)

-In Mexico, there were 409 NC machine tools in 1986 and more than half of machine tools imports are NC machines and the installed capacity has been estimated at around 1200 - 1400 in 1989; motor vehicle plants in the maquiladoras had around 50 NC machines installed.

3.1.2 Other developing countries

The measure of the diffusion of NC in other developing countries is difficult due to several shortcomings: (i) foreign trade figures published by international organizations (GATT, OECD, ECE) make no difference between conventional and NC machine tools; (ii) and developing countries statistics do not make this difference either.

In order to overcome this constraint, and sacrificing homogeneity for the sake of greater precision, national statistics from main exporting countries have been used. Tables 47 and 48 have been computed from the Japan trade statistics and the NIMEXE analytical tables(55) in the case of lathe imports, and milling, boring and machining centre imports by developing countries.

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(53) "Market reserve policies provoke growing conflicts as Brazil's technology lags", Business Latin America, April 3 1989.

(54) F. E. Erber: Co-Operation in industrial automation between Argentina and Brazil, UNIDO, 1990.

(55) Published by the Statistical Office of The European Communities.

Table 51: Import of lathes from Japan and Europe in 1987
(US$1000)

	NC	automatic	others	total	% NC	% auto
Republic of Korea	36013	0	5417	41431	87%	0
India	21071	3561	3935	28568	74%	.12
Taiwan (China)	16193	4380	1166	21739	74%	.20
China	12834	2407	4605	19846	65%	.12
Indonesia	11749	648	10348	22745	52%	.03
Iran	9799	1434	8538	19770	50%	.07
Zimbabwe	7836	6916	3351	18103	43%	.38
Singapore	7112	3903	3202	14217	50%	.27
Malaysia	4267	0	81	4348	98%	0
Thailand	3603	1838	2385	7826	46%	.23
Venezuela	3528	0	1738	5266	67%	0
Brazil	3365	121	3057	6544	51%	.02
Hong kong	3304	2931	534	6769	49%	.43
Chile	1847	0	0	1847	100%	0
Mexico	1779	1229	40	3048	58%	.40
Iraq	1572	1416	259[illegible]	5582	28%	.25
Pakistan	1231	0	1769	3000	41%	0
Lybya	1045	316	917	2277	46%	.14
Yugoslavia	478	0	0	478	100%	0
Philippines	429	291	405	1126	38%	.26
Argentina	138	1418	11	1567	9%	.90
Egypt	81	89	1132	1302	6%	.07
Algeria	0	7223	2688	9911	0%	.73
Saudi Arabia	0	0	921	921	0%	0
Bangladesh	0	0	413	413	0%	0
Burma	0	40	502	543	0%	.07
Burundi	0	0	63	63	0%	0
Colombia	0	0	6	6	0%	0
Ethiopia	0	0	1098	1098	0%	0
Gabon	0	0	0	0		
Kenya	0	0	40	40	0%	0
Morocco	0	0	40	40	0%	0
Nigeria	0	0	1027	1027	0%	0
Peru	0	0	851	851	0%	0
Senegal	0	0	0	0		
Tunisia	0	0	902	902	0%	0
Zaire	0	0	618	618	0%	0

Sources: Computed from NIMEX and Japanese trade statistics.

Table 52: Import of machining centers, boring and milling machines
(from Europe and Japan in 1987)
(US$1000)

	Machining Center	NC boring	NC milling	Non NC	TOTAL	Machining Center	NC
Algeria	0	0	0	1709	1709	0%	0%
Saudi Arabia	0	0	81	1763	1844	0%	4%
Argentina	374	0	867	1184	2425	15%	36%
Bangladesh	0	0	211	2204	2415	0%	9%
Brazil	6079	0	5344	3062	14485	42%	37%
Burma	0	0	0	0	0		
Burundi	0	0	0	0	0		
Chile	0	0	10500	5247	15747	0%	67%
China	14131	3285	11035	4494	32945	43%	43%
Colombia	589	0	29575	10988	41152	1%	72%
Republic of Korea	12682	21089	1649	11041	46461	27%	49%
Egypt	685	0	0	1350	2035	34%	0%
Ethiopia	0	0	0	1661	1661	0%	0%
Gabon	0	0	3470	2374	5844	0%	59%
Hong kong	3748	0	3104	10578	17430	22%	18%
India	9635	1203	9217	8453	28508	34%	37%
Indonesia	11447	1171	0	6488	19106	60%	6%
Iran	1426	0	6084	5279	12789	11%	48%
Iraq	0	0	2974	24	2998	0%	99%
Kenya	0	0	1008	98	1106	0%	91%
Lybya	707	0	260	187	1154	61%	23%
Malaysia	805	0	423	32	1260	64%	34%
Mexico	740	0	1007	0	1747	42%	58%
Morocco	0	0	0	33	33	0%	0%
Nigeria	0	575	0	0	575	0%	100%
Pakistan	1325	0	0	1149	2474	54%	0%
Peru	0	0	33	187	220	0%	15%
Philippines	1902	0	852	74	2828	67%	30%
Senegal	0	0	1813	2463	4276	0%	42%
Singapour	7463	0	10033	20085	37581	20%	27%
Taiwan (China)	21878	1780	2869	4531	31058	70%	15%
Thailand	2049	0	0	1856	3905	52%	0%
Tunisia	0	0	666	0	666	0%	100%
Venezuela	1057	0	668	2317	4042	26%	17%
Zaire	0	0	0	0	0		
Yougoslavia	7222	0	6661	1997	15880	45%	42%

Sources: Computed from NIMEXI and Japanese trade statistics.

Lathes Based on export figures (Table 51) it appears that 20 developing countries imported NC lathes in 1985, and 22 in 1987; however this scanty evidence does not show any trend of diffusion since a few countries purchased NC lathes either in 1985 or 1987 and 29 developing countries imported NC lathes during 1985 and 1987:

In Asia: China, Hong Kong, India, Republic of Korea, Taiwan Province of China, Indonesia, Malaysia, Pakistan, Philippines, Singapore, Thailand

In Latin America: Brazil, Mexico, Argentina, Peru, Venezuela, Colombia and Chile

In Africa and the Middle East: Iran, Iraq, Egypt, Saudi Arabia (1985), Zimbabwe (1985), Ethiopia (1985), Tunisia (1985), Senegal (1985), Nigeria (1985), Libya (1987)

In fifteen countries these imports represented more than US$1 million.

Machining centres Exports of machining centres from Japan and the EEC were directed to 20 developing countries in 1987, with fourteen importing for more than US$1 million (Table 52).

3.1.3 Prospects

Available studies predict rapid development of the NC machine tool market in middle income developing countries:

- In the Republic of Korea, the domestic demand for NCMT is expected to grow from 3700 units in 1990 to 7000 in 1995 and 14000 in 2000:(56) the motor vehicle industry will be the largest market, accounting for 55 per cent of the demand, followed by the machine tool industry.
- An AIDO study on machine tool industry in Arab countries has estimated that NC machine tool demand would grow at an

(56) Korea Institute for Economics and Technology: Mecatronics 1989 in Judet: L'industrie de la machine outil en Coree, UNIDO, 1990.

average rate of 10 per cent between 1990 and 2000.[57] while the demand for conventional machines would increase by 4 per cent annually.

-In the People's Republic of China, it has been estimated that the demand for CNC systems will increase from 2000 units in 1989 to 5000 (1995) and 7000 (1987)[58]

-In the case of Peru it has been estimated that the demand for NC machine tools could in the near future represent close to 40 per cent of total machine tool demand.

3.2 Choice of technology

Machine tools of different levels of sophistication are available to developing countries and they can all be put to economical use. It is only in very limited cases that advanced equipment are indispensable. (Box 23)

For a developing country the first option in selection of machining technology is simple conventional machines like centre lathes, shapers, milling machines.[59] However when bigger and heavier components are involved or a large production volume is needed, large labour force and great manual effort is required in using simple machines. Among the options which may be available are special purpose machines, transfer lines, NC machines, flexible manufacturing cells and flexible manufacturing systems. In most developing countries advanced equipments are imported and expensive and their use are justified only in very large volumes of production.

Among flexible automation technologies, NCMTs appear to be the most appropriate technology from the point of view of developing countries, because of the relative maturity of this technology. The skill-saving[60] nature is also a strong argument in favor of NCMTs. Available evidence suggests that where developing countries are already efficient users of conventional machine tools, they face few serious skill-related

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(57) AIDO: The development of machine-tool industry in Arab countries, 1987.

(58) Data from UNIDO project DP/CPR/89/017/A/01/37.

(59) See: Selection of appropriate machining technology, in A study of the machine-tool industry, NDFC Pakistan, 1988.

(60) Which should be assessed in taking into account the greater skill content of the repair and maintenance staff.

problems in using NCMTs though capital costs, scale requirements, available skills, protected markets and the availability of supplier support may present constraints in the wider application of this technology.

One of the main advantages of NCMTs is flexibility. However flexibility does not come out automatically.(61) NCMTs do offer economies of scope, but the experience of medium enterprises in industrialized countries shows that in many cases flexible equipment has been used to manufacture a group of similar components. A plant is organized to produce specific components, and in order to reap the benefits of the NCMT flexibility, one has to undertake a technological assessment of the plant and to implement organizational modifications. These organization changes may often be costly.

Lack of preparation of the enterprise prior to introducing NCMTs by suppliers of theoretical performances which have not been verified, lack of training and lack of technological mastering have lead in many cases to bitter experiences in industrialized countries. Table 49 shows the financial results of several types of technology investment: Computer Aided Design, Flexible Cells and NC Machine Tools. In many cases the introduction of these technologies has not led to financial reward in many firms in France; a survey made in the United Kingdom among 250 firms led to similar conclusions. (Table 53)

Investment in NCMT should be analyzed very cautiously following proven guidelines. (Figure 33) In order to advise engineering firms in developing countries, consulting services should be promoted through business associations or technical centers.

3.3 Organizational changes

One of the main challenges which will confront developing countries in the 1990's will be how to increase their industrial competitiveness in response to technological breakthroughs made in industrialized countries. Introduction of advanced equipment

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(61) P. Padilla: "Amelioration de la productivite d'exploitation des centres d'usinage et de tournage", CETIM informations No. 108, Decembre 1988.

appears to be a solution if some prerequisites are achieved through improvement in the management and organization of production: "*one does not acquire a Flexible Manufacturing System, one becomes a Flexible Manufacturing System*".(62) A sizable share of the gains from investment in flexible automation comes from organizational changes and, as strongly emphasized by several authors,(63) this suggests that these organizational innovations are in fact a software separable from technical change and may eliminate the need for acquisition of hardware. Among major organizational changes, one should mention Just-in-Time and the Kan Ban system. (Box 24)

3.3.1 Design and manufacturing

In several cases,(64) automation may be unnecessary and greater gains in efficiency can be obtained by adopting new management procedures in order to improve the co-ordination between different activities within a firm.

This is particularly the case between design and manufacturing. While design expenditures per se amount to only a small part of a product's total cost, design determines a major proportion of production, testing and servicing costs, that is because up to 90 per cent of production costs are in fact determined by design decisions made long before the blueprint reaches the shop floor.(65) In many companies personnel in these two activities communicate infrequently and a product is designed for a certain function and then handed ("thrown over the wall") to the manufacturing department. The designers sometimes do not take into consideration manufacturing problems and this leads to production delays. Close collaboration, labelled "concurrent

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(62) Bessant Integrated Manufacturing, UNIDO, 1987.

(63) Final Report of the Meeting of International Experts on a Programme for Industrial Automation in the Capital Goods Industry of Latin America Vienna, 27-28 November 1989, UNIDO and also K. Hoffman: Technological advance and organizational innovation in the engineering industry, Industry and Energy Department Working Paper, Industries Series Paper No. 4, The World Bank.

(64) See Made in America, regaining the productive edge which stresses this point.

(65) A Ford study has shown that 70 per cent of costs are frozen once the design is set (in MIT Working paper on industrial productivity).

Box 24: Organizational changes in developing countries

Examples of such changes are still anecdotal:

-In Singapore a Japanese subsidiary producing machine tools applied Just-In-Time principles since the early 1980s and as a result worker productivity increased by 70 per cent.

-In Venezuela, in an engineering firm that introduced organizational changes in the early 1980s productivity increased by 25 percent along with major improvement such as decline in customer returns and scrap

-In Brazil a survey among suppliers of components and motor vehicle assemblers has shown that the local car industry insists on more frequent deliveries: it is implementing "external" JIT and its strength allows it to transfer its inventories to the suppliers whose only alternative is to implement JIT. The car industry has not established more collaborative relationships with its suppliers, a situation which reflects the difficulty to adopt new organisational techniques throughout the industrial system as a whole.

Suppliers who have reorganized their production lines before implementing Kan Ban systems have achieved better results than the others.

Adapted from Hoffmann: Technolocial Advance and organizational innovation, Industry and Energy working papers, World Bank, 1990.
Bessant and Rush: Integrated Manufacturing, UNIDO 1987.
Roberto Rocha Lima: Implementing the Just-in-Time production system in the Brazilian car component industry, in IDS Bulletin 1989 Vol 20, Number 4.

engineering",[66] between design, production and marketing will allow to avoid these pitfalls. The availability of computerized tools makes it easier to spur cooperation between departments. Instead of passing information from one level to the other, with management approval at each step, teams can communicate electronically and make decisions themselves. This transformation is also encompassing suppliers.

Product function analysis can be made with the help of software packages in order to reduce the number of parts in a product and design can make automation unnecessary by making manual assembly more reliable.[67]

3.3.2 Step by step approach to automation

A large number of case studies in industrialized countries conclude that a decision to invest in flexible automation equipment is not likely to give the full benefit if it has not been preceded or accompanied by parallel changes within the organization: "*all you get when you put a computer into a chaotic organization is computerized chaos*".[68]

The strategy towards industrial automation should follow a step-by-step approach[69] starting with a reorganization aiming at productivity and flexibility improvements; changes will cover plant layout, development of skills, adoption of new working arrangements, planning and scheduling and production control. Another possibility of progressively changing from traditional manufacturing method into advanced manufacture on plant level is the establishment of an Autonomous Manufacturing Island[70] (AMI) for a selected group of parts. For this selected group of parts, conventional machines and CN controlled machines can be combined to undertake the various machining operations while production

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(66) Business Week: "A smarter way to manufacture, special report" 30 April 1990.

(67) Daniel E. Whitney: "Manufacturing by design", Harvard Business Review, July - August 1988.

(68) In John Bessant and Howard Rush: Integrated manufacturing Technology Trends, Series No. 8 IPCT.70, UNIDO October 1988.

(69) As advocated by the participants to the Expert Group Meeting on Industrial Automation (UNIDO, November 1989).

(70) A solution proposed by UNIDO/DIO/ENG in an on-going large machine-tool project in China.

Table 53: Payoffs from advanced manufacturing technology in percentage

technology	France	
	Financial success	
	Yes	No
CAD	25	75
FMC	10	90
Robots	10	90
NCMT	55	45

United Kingdom

Payyoff	Zero to to low	moderate to high
CAD	46	54
CAM	46	54
FMS	67	33
Robots	76	24

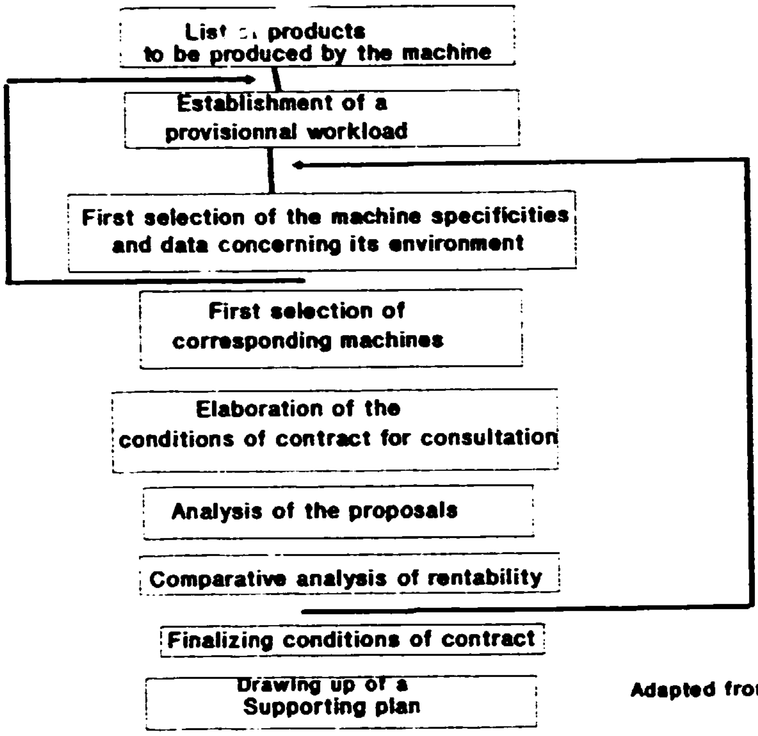
Sources:
France: CETIM
United Kingdom: interviews of 250 firms by the British Institute of Management, Cranfield 1986
in Bessant, UNIDO/IPCT.70 1988

planning and control, flows of materials and sequences of operations are optimized with the aid of computers. Included in this concept is alos tool management and maintenance of machinery and fixtures. The immediate investment for the establishment of an AMI is comparatively low and the AMI concept can easily be replicated for other groups of parts within the same/or other factories. Simultaneously changes from conventional machine tols to CNC machine tools can be effected as funds for investment and skilled labour and engineering forces become available.

Reorganization should extend beyond the firm level with the setting up of an appropriate subcontracting policy which can increase flexibility as shown in examples from Italy and Japan. (71)

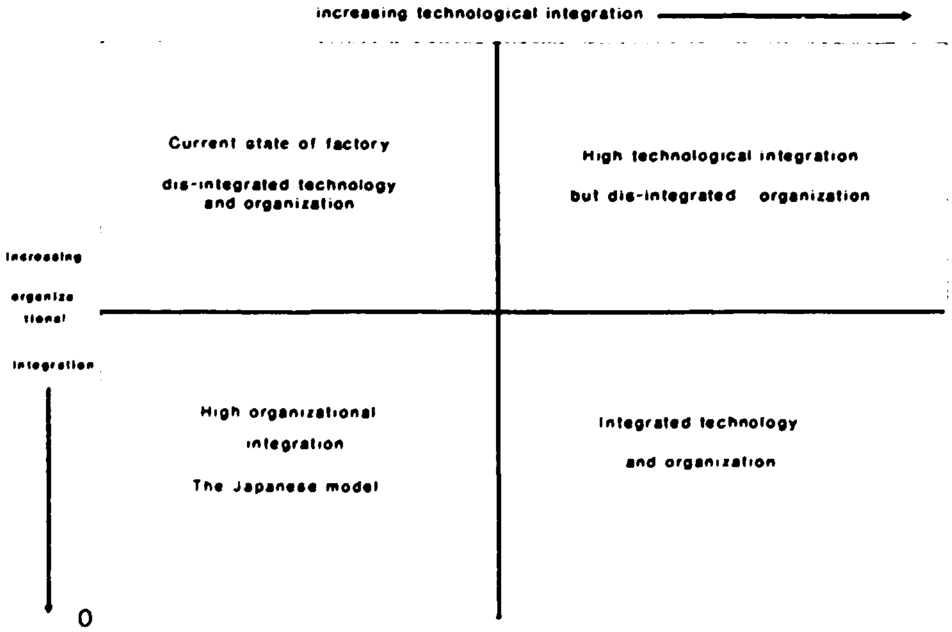
(71) In these two countries the existence of a large and flexible network of subcontracting firms appears to be correlated with the high level of diffusion of NCMT (see II).

Figure 33: Guidelines for the acquisition of a NC machine tool



Adapted from Padilla/CETIM

Figure 34: A step by step approach to integrated manufacturing



Source: John Bessant UNIDO Technology Trend Series Number 8