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MACHINE TOOL ISSUE PAPER

Paper prepared for the Expert Group Meeeting on Prospects for Industrial Sector Policies in Developing Countries Taking into Account the Repercussions of New and High Technology

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1. Introduction

As a part of the preparatory work for a UNIDO workshop on new technologies and industrial policies, to be held in April 1989, this paper presents an analysis of technical change and industrial development in the machine tool industry.

To a very large extent, new technology in the machine tool industry is synonymous with numerically controlled machine tools (NCMTs). In section 2, the technology of NCMTs is presented and its diffusion in the OECD countries is described. Its micro impact on users is discussed in section 3. In order to put the impact of new hardware into a larger perspective, we introduce the section with a discussion on new organisational forms which, by themselves, can lead to significantly higher productivity. Section 4 discusses the impact of an uneven global diffusion of NCMTs on international competitiveness and trade. Section 5 focusses on the machine tool industry itself and analyses how the nature of competition has evolved in some important products in the industry. Finally, in section 6, we discuss some policy implications for both the users of machine tools and for the machine tool industry in the developing countries.

2. The technology and its diffusion

2.1 The technology

Within the engineering industry, the machining function is central to the production process. About 20 per cent of the time spent by blue collar workers in the the Swedish engineering industry in 1981 was spent on operating machine tools. A further 10 per cent was expended on tasks intimately connected to machining, e.g. setting, repair and maintenance etc (Edquist and Jacobsson 1988:23).

For a very limited number of products, e.g. engine blocks, the production volumes have - during the recent decades - justified the investment in rigid, special purpose and automatic production systems. The bulk of engineering products, however, are produced in small and medium batches. Indeed, one source suggests that in Japan, this type of production accounts for 70-80 per cent of the value of production (Edquist and Jacobsson 1988:23). The workshops catering for a very diversified demand, e.g. 1,500 types of pumps, must have a very flexible production apparatus. The need for flexibility meant, until recently, that multipurpose and hand-operated machine tools were used. It was thus not possible to benefit from automation in the bulk of the engineering industry.

What has changed all this is the beyond doubt most important technological development in the engineering industry in recent time, namely the fusion between mechanical and electronics technology. The Japanese coined this new technology 'mechatronics'. The mechatronics revolution affects not only machine tools but also robots, measuring technology etc and the technical and economic feasibility to integrate machine tools with other machinery, on both the shop floor and in the office.

As far as machine tools are concerned, numerically controlled machine tools, (NCMTs), have become standard machine tools for a range of primarily metal cutting functions such as turning (lathes), milling, drilling and boring. A very brief description of the technology of NCMTs begins with listing the tasks that exist for the operation of a machine tool.

a) the workpiece is transported to the machine
b) the workpiece is fed into the machine and fastened
c) the right tool is selected and inserted into the machine
d) the machine is set, e.g. operation speed is determined
e) the movement of the tool is controlled
f) the tool is changed
g) the workpiece is taken out of the machine
h) the workpiece is transported to another machine tool or to a warehouse or to assembly
i) the whole process is overlooked in case of tool brakeages etc

In the 1950s, the first NCMT was developed. Instead of having a worker perform tasks (d) and (e), the information needed was put on a medium, e.g. a tape, and fed into a numerical control unit. By simply changing the tape, the NCMT could quickly be switched from the production of one part to another. Flexibility and automation was combined.

Because of the high costs and the unreliability of the NCMTs, the technology was not diffused until the the early 1970s when the numerical control unit was based on a microcomputer. A still more significant change was the introduction of micro computer based control units in 1975. The use of micro electronics was associated with lower costs, greater flexibility, greater reliability, simpler programming and the automation of other tasks than the two mentioned above. Automatic tool changing is normal today (tasks c and f), automatic material handling equipment is often attached to the machine tool (tasks b and g) and the task of overlooking the whole production process (task i) is beginning to be automated with the help of, for example, sensor techniques.

2.2. The diffusion of NCMTs

These technical and economic developments have greatly contributed to a fast diffusion of NCMTs since the mid 1970s. In table 1, we can see how the share of NCMTs in the total production of metal cutting machine tools rose in the leading machine tool producing nations of the OECD between 1976 and 1986. The share of NCMTs rose from 25 per cent to 67 per cent in this period. It is worth noting that this fast diffusion process has led to a stagnation in the demand for conventional machine tools in nominal dollars.

Table 1

Share of NCMTs in the total production of metal cutting machine tools in a number of leading OECD countries, 1976-1986

a		NCMTs	Conventional	Total
1976	USM	1,201	3,694	4,895
	%	25	75	100
1982	USM	4,173	6,065	10,238
	%	41	59	100
1984	USM	4,511	3,575	8,086
	%	56	44	100
1986	USM	7,405	3,732	11,137
	%	67	33	100

a) USA, Japan, FRG, France, Italy and UK.
Sources: 1976,82 and 84: Edquist and Jacobsson 1988:38-38; 1986: elaboration on data supplied by CECIMO.

For metal forming machine tools, the application of numerical control technique is still not so widely spread, with the exception of punching and shearing machines. In 1984, for example, only 19 per cent of the value of investment in metal forming machine tools in the FRG was made in numerically controlled machine tools (Edquist and Jacobsson 1988:40).

The two single most important NCMTs are (computer numerically controlled) CNC lathes and machining centres. A machining centre is a combined milling, drilling and boring machine. These two types of machines account for over 60 per cent of the value of production of NCMTs in the leading OECD countries. In table 2, we can see how CNC lathes have substituted for conventional lathes over the past decade. CNC lathes accounted for only 23 per cent of the total output of lathes in 1975, a figure which grew to over 50 per cent in 1980 and to nearly 80 per cent in 1986. It can also be seen that the output of conventional lathes was halved in nominal terms in these twelve years.

Table 2

The substitution of CNC lathes for conventional lathes in the major machine tool producing nations of the OECD (a)(in million USD and %)

Year	Prod. of conv. lathes USM	%	Prod of CNC lathes USM	%
1975	1,147	72	445	28
1976	1,057	62	498	32
1977	1,132	74	626	36
1978	n.a.	n.a.	938	n.a.
1979	1,515	54	1,310	46
1980	1,625	46	1,906	54
1981	1,554	49	1,639	51
1982	885	38	1,416	62
1983	634	33	1,280	67
1984	558	27	1,510	73
1985	542	24	1,714	76
1986	623	22	2,146	78

(a) USA, Japan, France, Italy, FRG and UK. Sweden is included in the data for 1975-1984.

Sources: 1975-1984: Jacobsson 1986:16; 1985-1986: elaboration on data supplied by CECIMO.

As far as machining centres are concerned, we can, in table 3, see how this technology has substituted for conventional milling machines. CNC milling machines do also exist as a substitute for conventional milling machines, but as is evident from the table, it is machining centres which have come to dominate as a source of milling technology. Whilst 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. The share of CNC milling machines seems to have stagnated at about 25 per cent whilst that of conventional milling machines shows a continous decline from 48 per cent in 1976 to 9 per cent in 1986. Again, the value of production of conventional machines declined in nominal terms.

Table 3

The substitution of machining centres and CNC milling machines for conventional milling machines in the major machine tool producing nations of the OECD (a) (in million USD and %)

Year	Machining centres		CNC milling		Conv. milling	
	Mill USD	%	Mill USD	%	Mill USD	%
1976	395	38	145	14	493	48
1982	1,232	51	633	26	557	23
1984	1,433	61	597	25	332	14
1986	2,398	65	937	26	340	9

(a) USA, Japan, FRG, France, Italy and UK.

Sources: 1976, 1982 and 1984: Edquist and Jacobsson 1988: 38-39; 1986: elaboration on data supplied by CECIMO.

The case of CNC grinding (and polishing) machines is somewhat different. In contrast to CNC lathes and machining centres, the diffusion of numerical control techniques started in a significant way only in the 1980s. As is shown in table 4, the share of CNC grinding machines was only 1 per cent in 1976 and it rose to 11 per cent in 1984. However, in 1987, it had risen to 36 per cent. One important reason for this delay in the diffusion of this technique appears to have ~~laid in~~ been the behaviour of the suppliers of the CNC unit. It was not really until recently that a numerical control unit which was suitable for grinding machines was put on the market. Up until recently, it was the, often very small, producers of the individual grinding machines which had to develop the control units too.

Table 4

The substitution of CNC grinding and polishing machines for conventional machines in the major machine tool producing nations in the OECD region (in million USD and %)

Year	Production of CNC grinding mach.		Production of conventional grinding machines	
	USM	%	USM	%
1976	10	1	480	99
1982	115	8	1,330	92
1984**	126	11	998	89
1987	710	36	1,989	64

* Japan, FRG, France, Italy and the USA
** Excluding UK and Italy

Sources: 1976-1984: Edquist and Jacobsson 1988:38; 1987: Data received from CECIMO and NMTBA (1988/89)

2.2.1 The industrial distribution of NCMTs

In table 5, we can see the industrial distribution of NCMTs by machinery groups in Japan and the USA. The general machinery sector, broadly ISIC 382, accounts for approximately half of the installations. The transport equipment sector is the second largest user of NCMTs.

At a more detailed level, one can on the basis of US data specify eight subsectors which are feeling the greatest impact of NCMTs. These can be listed as (Edquist and Jacobsson 1988:30):

- Construction, mining and material handling machines
- Aircrafts and parts
- Miscellaneous machinery, except electrical
- Miscellaneous transport equipment
- Engines and turbines
- Metalworking machinery
- General industrial machinery
- Special industrial machinery

This list simply shows that NCMTs are mainly used in mechanically based industries where metal cutting is an important part of the production process.

Table 5

Distribution of the stock of NCMTs by sector in Japan (1981) and the USA (1983) (in % of the stock)

	Japan*	USA*
General machinery	43	51
Electrical machinery	16	10
Transport equipment	23	15
Precision machinery	7	5
Metal products	5	14**
Casting/forging products	2	3***
Miscellaneous	4	2

* The Japanese inventory covers plants with 100 employees and more. The USA inventory covers all sizes

** Fabricated metal products

*** Primary metals

Source: Edquist and Jacobsson 1988:28

2.3 The diffusion of systems

Whilst the rapid diffusion of stand alone NCMTs has been the main feature of the diffusion of new technology in the engineering sector since the mid 70s, it is nevertheless the diffusion of NCMTs incorporated into systems which will dominate the future. The most important manifestations of system development are smaller ones, commonly called flexible manufacturing modules (FMMs) and flexible manufacturing cells (FMCs). A FMM is a stand alone NCMT which has an automatic material handling unit attached to it, e.g. a robot, which allows for some unmanned production. A FMC is comprised of several machine tools (2-5) linked by an automatic material handling unit and controlled by a common information system. There are also larger systems, commonly called flexible manufacturing systems (FMS) which consist of several FMCs or a larger number of machine tools, with automatic material handling facilitites and a common information system.

Data on the diffusion of systems is notoriously difficult to find, partly because of definition problems. The larger systems (FMS) are most studied and ECE (1986) suggest that there were 350 FMS in the world around 1984/85. All in all, 309 of these were studied and were found to contain 2,139 machine tools. This would mean that less than one per cent of the worlds NCMTs were incorporated into FMSs.

The only comprehensive study which was found covering the diffusion of the three types of systems is on Sweden (Edquist and Jacobsson 1988:73-78). In table 6, we reproduce some key data on the estimated stock and flow of NCMTs, FMMs, FMCs and FMSs in Sweden around 1985. From the table, we can observe that a) a fairly small part of the stock of NCMTs was incorporated into a system in 1985; b) however, around 30 per cent of the flow of NCMTs was incorporated into some kind of system; c) the diffusion of systems take place mainly in the form of FMMs and FMCs.

What these figures would tend to suggest is that we are probably in a rapid diffusion process for systems, primarily the smaller types. However, we cannot generalize from the Swedish example to the entire OECD area. As is tentatively shown in Edquist and Jacobsson (1988:74-76), the Swedish industry is ahead of other European countries in the use of systems, as is the case with other automatic capital goods (Edquist and Jacobsson 1988:104). What is probably to be expected is, however, that the Swedish experience shows the direction in which other countries will move in a few years time.

3. The micro impact of NCMTs on users

3.1 Organisational changes versus hardware changes

The impact of new technology on the (total factor) productivity on the shop floor is not a function of only new hardware. The

Table 6 Key data on the estimated stock and flow of NCMTs, FMMs, FMCs and FMSs in Sweden

	Stock[a]			*Flow*[a]		
	(1)	(2)	(3)	(4)	(5)	(6)
Technique	*Units*	*Total no. NCMTs incorporated in system*	*Share NCMTs in (2) in total stock NCMTs (%)*	*Units*	*Total no. NCMTs incorporated in system*	*Share NCMTs in (5) in total flow NCMTs (%)*
NCMT	6,000	—		700	—	—
FMM	n.a.	n.a.	n.a.	80[b]	80	11
FMC	200	400–500	6.7–8.3	50	100–125	14–18
FMS	15–20	90–120	1.5–2.0	3[c]	17[b, c]	2

[a] Flow refers to September 1984 to August 1985 and stock refers to 1985.
[b] Only those including CNC lathes and machining centres.
[c] Excluding those made in-house by the user on the basis of already existing NCMTs.
Source: Edquist and Jacobsson (1988: 75)

ability to organise the proper use of both labour, machinery and materials is certainly an equally fundamental factor determining shop floor productivity. Organisational ability has many aspects to it. An important one, on which we shall focus on here, is the formal organisation of the flow of materials and the set up the machines.

Parallell to and often associated with the introduction of new machine tools (and other micro electronics based hardware) is the use of 'new' organisational forms. 'New', because these forms, primarily Just in Time (JIT) and Group Technology (GT) date way back to the 1930s and the 1950s respectively (Watanabe 1987, Fleury 1988).

JIT, which is at the core of Japanese production management and productivity improvement (Voss 1986), is well described in its essence by Watanabe (1987:75):

> " The philosophy underlying this system is that the workers obtain just the right quantitites of the right kinds of parts and components at the right moments, to avoid stockpiling along the production lines. This minimises both the cost of inventory carrying and the space required for that purpose. In order to achieve this goal, work at a point of the production process needs to be done strictly according to the orders received from the next stage of the work sequence. The whole process starts from the final assembly line, and the required kinds of quantities of work pieces ... are communicated backwards all the way down to the casting, forging and stamping shops."

JIT is not a question of only the relationship between an assembler and the suppliers of raw materials and components, but refers equally, as is clear for the citation, to organisational changes within a company and workshop.

GT refers to the case where families of products are identified, for example components for pumps of different sizes, and the organisation of a production line in which all or many of the production processes that are require to complete the component are present. Such an organisation is distinct from the traditional functional layout where machines of a specific type, e.g. milling machines, are grouped together.

The primary objective of implementing these 'new' organisational forms is to reduce the costs for stocks and work in progress. Other benefits might, however, accrue to the firm. It could be mentioned that a more 'straight' production process using GT does reduce the number of planning points and therefore, the need for white collar workers.

Both GT and JIT have been applied to conventional machine tools but their use is frequently associated with the adoption of NCMTs. It would appear as if the advent of micro electronics, both in the machine tool and as the means of communication, has led to a widened scope for the application of these organisational forms (Kaplinsky 1987; Fix-Sterz and Lay 1987). Indeed, a FMC or a FMS can be seen as one manifestation of the GT principle where the loading/unloading and the transport of the workpiece between the machines is automated.

3.2 Choice between numerically controlled machine tools and conventional machine tools

The choice between NCMTs and conventional machine tools is a rather complex problem. In some, very limited, instances, there is no choice if the required precision should be met. This could be the case with some military products. However, this argument, which is often made, for the choice of NCMT could equally well reflect poor skills among the operators of conventional machine tools (Edquist and Jacobsson 1988:142).

Given that there exist a real choice between NCMTs and conventional machine tools, two main factors can be identified (Jacobsson 1986:16-20):

1. The cost of preparing the machine tool (setting and programming it etc). Let us call this the fixed cost.

2. the cost of cutting or forming the metal, i.e. the cost of the actual machining. Let us call this the variable cost. This variable cost is a function of three factors:
   a) the cycle time, which is the time it takes for the workpiece to be machined;
   b) the cost of capital per unit of time, i.e. both the cost of the machine and the interest rate;
   c) the cost of labour for operating the machine tool per unit of time.

Using these main factors, the choice of machine tool becomes a function of the cost of preparation (fixed costs) and the cost of actual machining (variable cost). Let us illustrate with an example, see Figure 1.

In this example, we compare the choice of CNC lathes with engine lathes and automatic lathes. The engine lathe is a simple lathe which is manually operated. It is very cheap in comparison with other lathes but the cycle time is long which implies high variable costs, especially when labour is dear. The fixed costs, however, are very low. The CNC lathe has a shorter cycle time which may mean that the variable costs are lower than for engine lathes, especially when labour is dear. The fixed costs have traditionally been higher than for engine lathes due to need to make tapes or computer programs, but the the program costs have been reduced substantially in the past. In addition, once a computer program has been made, the fixed costs of preparing another batch of the same part is close to nil. This means that the more often the production of particular part is repeated, the lower are the fixed cost of using a NCMT in relation to other types of lathes. The fixed costs may, in some instances, even be lower than for engine lathes. The automatic lathe is characterized by very short cycle time and the use of very little labour, implying low variable costs. The fixed costs are however very high.

The characteristics of the different types of lathes in our example mean that engine lathes would normally be used for batch sizes smaller than X1 in Figure 1, CNC lathes would be

16A

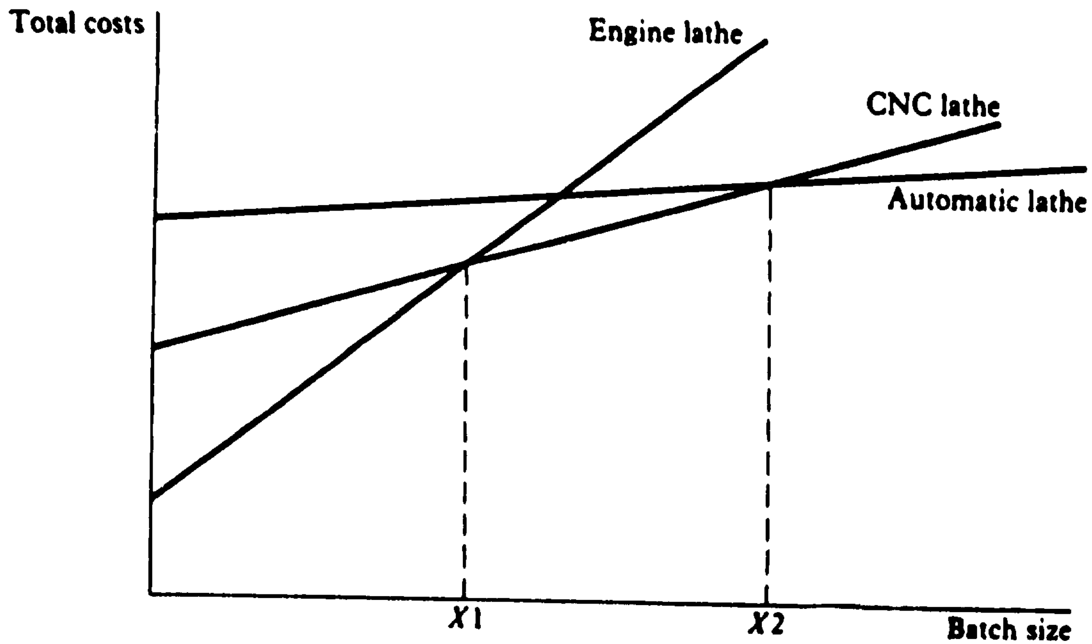

Figure 1 Illustrative example of choice of technique between engine lathes, CNC lathes and automatic lathes.

used for batch sizes in between X1 and X2 whilst automatic lathes would be used for batch sizes larger than X2. CNC lathes are thus more flexible than automatic lathes but normally less flexible than engine lathes. In some situations, characterized by frequent, repetitive production of an identical part, CNC lathes could, however, have lower variable and fixed costs that engine lathes.

The precise values of X1 and X2 would of course vary from country to country and from firm to firm depending on a number of factors. Of immediate concern is the price of labour and capital, where we include both the price of the machines and the interest rate. A high price of labour would mean that the variable cost of engine lathes would rise vis a vis the variable costs of other types of lathes. All the lines in figure 1 would then become steeper, but that of the engine lathe would be most affected. This would mean that the break even point between engine lathes and CNC lathe would be to the left of X1. Similarly, a high price of capital would push up the variable cost of CNC lathes more than that of engine lathes.

Hence, if we have a situation (which is frequent in the developing countries) where a) the price of labour is low and b) the price of the CNC lathe is high (for example due to a protected trade regime for the machine tool industry which would tend to affect the price of the more complex CNC lathe greater than that of the simpler engine lathes), the scope for applying CNC lathes would be reduced.

The three key factors determining the choice of technique are thus:

- the batch size normally produced and the frequency by which it is produced;
- the price of labour;
- the price of capital.

Other factors do, of course, influence the choice of technique. If we disregard such factors as the status derived from having new technology in the plant, the scope for keeping a high capacity utilization matters as well as the scope for reducing work in progress. The former can be function of the availability of the precise skills to not only use NCMTs (both plan the use and to operate) but also to repair and maintain the NCMTs. The availability of these skills would tend to vary between the various technologies.

Of course, the substitution of NCMTs for conventional machine tools, as shown in section 2.2., has been associated with a movement of X1 to the left and of X2 to the right. This has not only been due to changes in the labour costs but, perhaps more importantly, in changes in the cost/performance ratio of the machine tools (as discussed qualitatively in section 2.1).

As would be expected when such a fast and relatively thorough substitution process occurs, it is well established that stand alone NCMTs are economically efficient in a range of combinations of prices of capital, labour and batch sizes (and their frequencies). The degree of saving on the cost of production of a part, varies, however greatly from case to case. In one study in the Federal Republic of Germany (Rempp et al 1981) the range of total cost reduction varied from 3 to 40 per cent. In a Swedish study of six firms (Elsässer and Lindvall 1984) five firms decreased their cost of production whilst one firm increased its cost of production. The maximum cost reduction amounted to around 50 per cent.

The use of NCMTs is labour saving (as would be expected) but it can also be capital saving per unit of output. There is some evidence pointing in this direction from Sweden (Edquist and Jacobsson 1988:34) although it is far from certain that this is a general pattern neither in Sweden, nor in other countries. What is clear, however, is that the use of NCMTs can be very skill saving. Taking into account only the skills of the operators, the programmers and the setters, it has been calculated (Jacobsson 1986) that the savings in skills can amount to as much as 82 per cent. A counter acting force would be the increased skill content of the repair and maintenance work which require multi skilled workers. On the whole, however, in percentage terms, per unit of output, it is fair to say that the skill savings are greater than that of labour saving which in turn is greater than that of capital saving (if there is any).

4. International implications of the global diffusion of NCMTs

4.1 An overall pespective of new technology as a determinant of international trade and competitiveness

Unfortunately, much of the literature on the impact of new technology on international competitiveness proceeds as if the determinants are fully or mainly a matter of relative production costs. This focus on production costs, and on factor prices, has its intellectual origin in the factor proportion trade theory. As is well known in the literature (Gray 1980), this theory is inadequate in explaining existing trade flows, and therefore, firms' and countries' international competitiveness. The technology gap trade theory (Hufbauer 1966, Soete 1981), as well as much literature on the border between economics and management (Caves 1980), emphasise, in contrast, a range of other factors. Firms are seen as striving to create unique assets which make them superior to their competitors. These superior, firm specific, assets are basically dynamic in character and are hence, augmented by the accumulation of experience in R&D, design, production and marketing. Static economies of scale can further prolong and reinforce any advantages derived from an early technological breakthrough or from a faster accumulation of experience in any or all functions of the firm. Thus, productions costs, which are partly influenced by the technology used, is only one out of many determinants of competitiveness.

Furthermore, the structure of costs in a modern engineering company is heavily skewed away from production proper, e.g. machining. In the case of a pump manufacturer, the manufacturing proper accounted for only 20 per cent of the total cost of the company (Edquist and Jacobsson 1988). In a CNC lathe producer, the share was even less (Jacobsson 1986). A stylized cost structure of a modern engineering firm could look as in table 7. NCMTs constitute part of the costs of machining which may account for in the order of 15 per cent of the total cost of the firm. Hence, we can immediately see that any productivity increases from the introduction of NCMTs will be diluted when we aggregate up to the firm level.

This is not to say that the diffusion of NCMTs will not have any effects on international competitiveness but only to point to both the range of factors determining international competitiveness and to the necessarily very limited effects that productivity improvements in one function (machining) can have on the firm taken as a whole.

Table 7

Stylized cost structure of a modern engineering firm

R&D&E	7%
Externally sourced components and materials	40%
Machining	15%
Assembly	8%
Marketing	30%

4.2 The global diffusion of NCMTs

NCMTs are clearly being diffused in both the developed countries (as shown in section 2.3) and in the Newly Industrializing Countries (NICs). In table 8, the estimated stock (column 1) of NCMTs is given for some NICs and some developed countries. Among the NICs, we can see that Korea is the largest single user of NCMTs, with a stock of 2,680 units in 1985, followed by Brazil and India. Among the developed countries, Japan is the largest user with 118 000 units installed by 1984. In terms of density (column 2) in the use of NCMTs, the NICs are very far behind the developed countries. The ~~most dense~~ leading developing country in terms of using NCMTs, Korea, had a density only about half of the least dense developed country, the UK. Taken jointly, the five NICs (excluding Argentina) had a density of 1,665. The developed countries had a density of 14,230 which is 8,5 times higher than for the NICs.

Table 8

The stock of NCMTs and the density in their use in some NICs and in some developed countries*

	(1) Stock (units)	(2) Density**
Argentina	500	na
Brazil	1,711	1,033
India	1,178	807
Korea	2,680	5,176
Singapore	700	4,526
Yugoslavia	1,232	1,720
FRG	46,435	11,376
Japan	118,157	22,399
Sweden	6,010	22,177
UK	32,566	10,505
USA	103,308	11,728

* the stock data ranges from 1983 to 1985 whilst the data for the number of employees in the engineering industry is from 1979 or 1980.
** number of NCMTs divided by million employees in the engineering sector.

Source: Edquist and Jacobsson 1988: table 12.1

The NICs are also behind in terms of the <u>flow</u> of NCMTs, measured as the share of NCMTs in the total machine tool investment. This is clearly shown in table 9 where we can see that this share amounted to between 7 and 23 per cent for some NICs whilst it ranged from 40 to 62 per cent in some OECD countries.

Table 9

Estimated yearly investment in NCMTs in relation to total investment in machine tools in some NICs and in some developed countries

	NCMTs/MT (in %)
Brazil (1982)	11.1
India (1984)	13.0
Korea (1984)	23.2
Taiwan (1986)	13.7
Japan (1984)	54.3
Sweden (1984)	59.4
UK (1984)	62.4
USA (1984)	40.1

Sources: Edquist and Jacobsson 1988: tables 3.2 and 9.2; Korea Machine Tool Manufacturers Association (1987): 488-491 for Taiwan.

4.3 The impact of NCMTs on trade

It is clear that NCMTs can have significant effects on the productivity of machining (see section 3.2). It is also clear that the developed countries are adopting NCMTs to a much greater extent than do the NICs. Obviously, the developed countries have so far benefitted more from this new technology than the NICs. In turn, this implies that the developed countries have strenghthened their competitive position vis-à-vis the NICs in those product groups where NCMTs are used.

It would seem as if the product groups mostly affected by NCMTs in the developed countries are predominantly produced under import substituting schemes in the NICs. On the whole, the export perfomance of the NICs in the mechanically based industries is rather poor (Edquist and Jacobsson 1988:191). Whilst it would be tempting to conclude that it the uneven global diffusion of NCMTs has contributed to this poor performance, it is important to remember that machining constitute only a small part of a firm's total costs and there are a great number of other determinants to competitiveness than relative production costs. Whilst one can not exclude the possibility that NCMTs have had a significant negative impact on the competitiveness of the NICs in these areas, it is probably so that the main causes can be found in the technical complexity of these products and their marketing intensity. What can be concluded, however, is that the ambitions of the NICs in becoming internationally competitive in the product groups mostly affected by NCMTs has come up against yet another obstacle, namely an improved cost competitiveness of the developed countries.

5. International implications for the machine tool industry

5.1 Some general features of the machine tool industry

A metalworking machine tool is a power driven machine, not portable by hand while in operation, which works metal by cutting, forming, physico-chemical processing or a combination of these techniques" (MTTA 1983:2). It has been estimated that there are some 3,000 different types and sizes of machine tools ranging from less than one ton to over sixty tons and ranging in unit prices from less than one thousand pounds to over 400,000 pounds (MTTA 1983:2).

The machine tool industry is therefore a very heterogeneous industry. The heterogeneity of this particular industry is noted by the Boston Consulting Group (1985:21) which explains that " ...almost 100 strategically different business segments have been identified in metal cutting and metal forming, many of which have numerous subsegments." This implies, inter alia, that an analysis of the impact of new technology on the machine tool industry can not be undertaken at the level of the entire industry. Some broader features and trends can, however, be identified at this level.

The machine tool industry is very small in national terms. According to Jones (1983:1), it accounts for between one and three per cent of manufacturing employment in the developed countries, generally speaking. Historically, however, the machine tool industry has certainly had a proportionally greater impact on the industrial arena since it has been an important transmission mechanism whereby the latest machining technology has been diffused throughout the economies. As MTTA (1983:2) puts it: " No modern product exists without machine tools, if not directly involved then certainly only one remove away." It is the centrality of the machine tool in modern industry as well as its perceived role as a generator and transmitter of new technology which have led to the belief that the industry is of strategic importance.

Perhaps the most notable feature of the industry is that its producers are relatively small. In the U.K., about 80 per cent of the employees in the machine tool industry work in firms with less than 500 employees (MTTA 1983a:22). In the US in 1982, there were 1,392 establishments in 1,290 companies. Only eight establishments had more than 1,000 employees. These establishments accounted for less than 20 per cent of total employment (NMTBA 1987/88: 70-71). Thus, the industry is very atomistic and the average establishment is very small. This applies to leading firms in the industry as well. A leading Japanese firms producing computer controlled machine tools has 1,700 employees. Indeed, if the entire US machine tool industry was combined into one firm, its sales would rank 142nd on the 1986 "Fortune 500" listing of America's largest manufacturing companies (NMTBA 1987/88:60).

5.2 Production and trade in machine tools

In table 10, we can see the largest producers of machine tools in the world in 1985. Exports and imports are also shown. The largest producers are by far Japan, FRG, Soviet Union, United States and Italy. Jointly, they accounted for more than seventy per cent of production of machine tools in 1985. Among the developing countries, China ranks highest as number 10, whilst Taiwan is number 13, Brazil number 14 and Korea and India follow with number 18 and 20 respectively. Jointly, the developing countries accounted for six per cent of the output of the countries listed in table 10. In 1972, the developing countries, listed in a similar table, accounted for only 2.6 per cent (UNIDO 1975).

Table 10

World machine tool production and trade, 1985 (revised)
(million of U.S. dollars)

Country	Production	Export	Import
1. Japan	5,317	2,179	219
2. FRG	3,168	1,807	586
3. USSR	3,036	210	1,387
4. U.S.A.	2,718	452	1,739
5. Italy	1,116	708	196
6. Switzerland	822	836	170
7. GDR	730	759	96
8. France	445	209	358
9. U.K.	418	322	386
10. PRC (a)	341	14	223
11. Czecho-slovakia	338	253	67
12. Romania	324	55	75
13. Taiwan	278	202	76
14. Brazil (a)	265	28	39
15. Spain	253	152	59
16. Yugoslavia	239	143	69
17. Canada	199	105	334
18. Korea	180	23	229
19. Hungary	176	138	91
20. India	166	22	162
21. Sweden	161	139	157
22. Poland	148 (a)	71	87
23. Bulgaria	133	80	145
24. Israel	96	83	57
25. Belgium	93	133	166
26. Austria	80	94	117
27. Denmark	53	42	75
28. Netherlands	38	69	136
29. Australia(a,b)	36	7	109
30. Singapore	34	84	143
31. South Africa	29	1	366
32. Finland	20 (a)	23	70
33. Mexico (a)	18	3	146
34. Portugal	11	7	23
35. Hong Kong	1 (a)	6	52
Total	21,480	9,457	8,406

(a) rough estimte from fragmentary data
(b) Year ended June 30

Source: NMTBA 1987/88:166

The industry is, on the whole, fairly internationalized as far as trade is concerned. In 1985, 44 per cent of output was exported. Smaller countries generally have a higher export ratio than do the bigger countries. With the exception of Taiwan, the developing countries have low export ratios.

The principal trade flows in machine tools is shown in table 11. Japanese and EEC exports to the USA are very large as are EECs export to the developing countries and to the Comecon countries. The table particularly shows the weak position of the USA. The import share of apparent consumption of the USA rose dramatically in the past decade, from 21 per cent in 1978 to 49 per cent in 1986. For numerically controlled machine tools, the import share rose from 23 to 61 per cent. (NMTBA 1987/88:126). The deteriorating position of the US industry is a main feature of a changing global trade pattern in machine tools in the recent decade. The main suppliers to this, the second largest market in the world after Soviet Union, was in 1986, Japan (841 million USD), FRG (280) and Taiwan (116) (NMTBA 1987/88:129). Another, although minor, feature is the growing strength of the developing countries, in particular Taiwan. As noted above, Taiwan is the third largest exporter to the USA. In total, in 1986, the LDCs exported machine tools to a value of 258 million USD to the OECD countries.

Table 11

Principal trade flows in machine tools in 1985 (million USD)

	Exporters			
Importers	USA	Japan	W. Europe	LDCs
USA	-	840	644(b)	159(c)
Japan	20	-	130(b)	23(d)
W. Europe	63	339	-	76(e)
Comecon	1	127	552(b)	na
LDCs	145	489(a)	884(b)	na

(a) Mexico, China, Indonesia, Korea, Malaysia, Singapore and Taiwan.
(b) EEC
(c) Brazil, China, Singapore, Korea, Taiwan. The data is for 1986
(d) Brazil, Hong Kong, Korea, Taiwan, China and Singapore. The data is for 1986
(e) Mexico, Nicaragua, Columbia, Brazil, Argentina, 'Other Near East', India, Singapore, China, South Korea and Taiwan. The data is for 1986.

Sources: Elaboration on NMTBA (1987/88:138,139, 186.203); NMTBA (1988/89: 184); Korea Machine Tool Manufacturers' Association (1987: 240-249, 364-381,396-401

5.3 The structure of the industries producing CNC lathes, machining centre and CNC grinding machines

5.3.1 Trends in market shares for CNC lathes and machining centres within the OECD ~~community~~

In tables 12 and 13, market share data is listed for the three regions; Japan, Europe and the USA with respect to CNC lathes and machining centres.

Table 12

The production of CNC lathes in Japan, Europe and USA 1975-1986 (in units and %)

Year	Japan		Europe*		USA		Total
	No	%	No	%	No	%	No
1975	1,359	30	1,535	34	1,640	36	4,524
1977	3,900	53	2,332	31	1,178	16	7,410
1979	8,065	58	3,505	25	2,354	17	13,924
1981	12,133	64	4,904	26	2,021	10	19,058
1983	10,020	65	4,106	27	1,203	8	15,329
1984	16,555	72	4,818	21	1,524	7	22,897
1985	19,804	73	5,564	21	1,420	6	26,068
1986	15,988	68	6,438	27	1,163	5	23,589

* 1975-1984: FRG, France, Italy, UK and Sweden. In 1985 and 1986, Sweden is excluded and in 1986, Spain is included.

Sources: 1975-1984: Jacobsson 1986:33; 1985-1986: elaboration on data supplied by CECIMO and NMTBA 1987/88:207

Table 13

The production of machining centres in Japan, Europe and the USA, 1978, 1982 and 1986 (in units and %)

Year	Japan		Europe		USA		Total
	No	%	No	%	No	%	
1978	1,377	39	649(a)	18	1,486	42	3,512
1982	6,936	73	1,335(b)	14	1,265	13	9,536
1986	10,882(d)	70	3,784(c,d)	24	918(d)	6	15,584

(a) UK, FRG and Italy. The UK data is from 1979.
(b) UK, FRG and Italy.
(c) UK, FRG, Italy, France and Spain.
(d) 'Machining centres and transfer lines, NC'.

Sources: 1978 and 1982: Edquist and Jacobsson 1985; 1986: elaboration on data supplied by CECIMO.

What is evident from the tables is that a very marked shift in the geographical location of production has taken place to the benefit of Japan. The dominance of Japan is painful for other countries, especially for the US industry which has nearly been annihilated; its share of production of CNC lathes fell from 36 per cent in 1975 to 5 per cent in 1986! Similarly, in machining centres, the US share fell from 42 per cent in 1978 to 6 per cent in 1986.

The Japanese dominance in the output of CNC lathes and machining centres is reflected in their strong position in the US and European markets. Of the Japanese production of 10,882 machining centres in 1986, 5,893 was exported (54%). The equivalent figures for CNC lathes were 15,988 and 8,673 (55%). More than half of the the export went to the US where the Japanese have captured the bulk of the market, see table 14.

The European industry has managed to keep a larger share of its market. In the case of CNC lathes an estimated third of the market (in units) of FRG and UK was held by the Japanese. At the same time, the Japanese import of CNC lathes and machining centres is minimal.

The Japanese dominant position overseas has led to the trade restrictions imposed by both the US and the Common Market in the form of 'voluntary' export restrictions by Japanese producers. The collapse of the US industry has even led to 'voluntary' export restrictions by Taiwanese producer. These are from 1987 allowed to export only 202 NC lathes and 220 machining centres to the USA. Exports to Europe is still free for Taiwan (Metalworking, Engineering and Marketing 1988:50).

Table 14

Japanese share of the US market for CNC lathes and machining centres in 1986 (in units)

	Machining centres	CNC lathes
Production	10,882	15,988
Export	5,893	8,673
Export to the USA	3,435	4,456
Apparent consumption in the USA	4,810	6,613
Japanese share of the US market	71%	67%

Source: NMTBA 1987/88: 101, 132,144, 200, 202

5.3.2 Structural composition of the OECD CNC lathe and machining centre industries

The process of maturation and diffusion of CNC lathes and machining centres was closely connected to the behaviour of, and structural change within, the supplying industry. In the early 1970s, the supplying industry had, as a rule, not yet identified these machine tools as the key product(s) around which they should define their strategies. Although there was some trade in NCMTs, the business relations were mainly of local or regional character. The volume of production of each producer was small and the main customers were large firms. These firms often demanded high performance machines, frequently with custom designed features.

In the mid 1970s, some Japanese firms started to apply a business strategy which could be labelled an overall cost leadership strategy (Porter 1980). The firms had as their basic objectives to penetrate very large parts of the engineering industry. The key factor involved in the definition of their strategy was the design of lower performance, smaller and lower cost CNC lathes and machining centres than hitherto had been available to the customers. These machines were primarily, but not exclusively, aimed at the smaller and medium sized firms. So the Japanese firms deliberately tried, and succeeded in, opening up a new market for this technology The success in doing so allowed them to to grow in size and to capture, hitherto only potential, significant economies of scale. As a consequence, the size of the leading firms grew in a phenonemal way. Available data on the size of CNC lathe and machining centre producing firms are summarized in tables 15 and 16. It is apparent that the Japanese firms have become very large in these industries and that it seems that the process of growth is continuing. Not surprisingly, the concentration ratio is fairly high. The largest five Japanese firms have 71 and 54% of the Japanese production of CNC lathes and machining centers respectively whilst in the European case the five largest firms have an estimated 55 per cent of the CNC lathe production. Data for machining centres in Europe is not available.

Table 15

Production of machining centres by leading firms in Japan, 1975-1987, (in units)

	1975	1978	1982	1987
Top firm	44	165	900	1,354
Average of following four firms	39	76	675	869

Source: Jacobsson (1985) and elaboration on Metalworking, Engineering and Marketing September (1988) for 1987.

Table 16

Production of CNC lathes by the leading firms in Europe, USA and Japan 1975-1987, (in units)

	Top firm				Average of following four firms			
	1975	1978	1982/4	1987	1975	1978	1982/4	1987
Europe	na	250	1,000	na	na	210	410	na
USA	na	na	520(a)	na	na	na	na(b)	na
Japan	270	1,000	2,500	2,895	105	525	1,400	1,970

a) 1980
b) the total production of CNC lathes in the USA amounted to 2,379 in 1980, 2,021 in 1981, 1,489 in 1982. If the leading firm produces around 500 units, the remaining firms must produce substantially less per firm. This is even more apparent in 1986 when total production was only 1,163 units.

Source: Jacobsson 1985 and 1986 for the period 1975-1982/4; Metalworking, Engineering and Marketing, September 1988 for 1987.

A distinctive feature of the leading Japanese firms is that they operate in both these industries. The four leading Japanese firms and their production of CNC lathes and machining centres is listed in table 17. It is obvious that we have here firms which have become quite large in the hitherto fragmented machine tool industry. These four firms alone produced 13,769 units in 1987 which can be compared with a total production in the major OECD countries of 31,872 units in 1986. This means that these four firms have in the order of 40 per cent of the major OECD countries' output of CNC lathes and machining centres!

Table 17

Production of CNC lathes and machining centres by four leading Japanese firms in 1987

Firm	Machining centres	CNC lathes	Total
Mori Seiki	1,354	2,865	4,219
Yamazaki	1,264	2,820	4,084
Okuma	993	2,895	3,888
Hitachi Seiki	587	991	1,578

Source: Elaboration on Metalworking, Engineering and Marketing, September 1988: 17,18,26.

These firms make up the core of a strategic group which could be labelled overall cost leadership group (Porter 1980). The group has other members too, but which are much smaller, e.g. Ikegai (Japan) and the Italian producer Olivetti (which also is a large producer of numerical control units).

Pursuing this strategy involves producing a standard product of medium performance which is sold to mainly smaller and medium sized firms with a fairly high price elasticity of demand. Price is therefore relatively low. The marketing is frequently done through independent dealers and the R&D involves developing machines which are easy to use. Emphasis is also given to designing a machine which can be manufactured at low cost. A large volume of output is required. A few of these firms produce their own CNC unit, e.g. Okuma and Yamazaki. Okuma has done so for decades whilst Yamazaki developed its own more recently since Fanuc, the leader in the world of numerical control systems, refused to collaborate in designing a unit that would be extremely easy to use (Jacobsson 1986:85-86). The overall cost leadership strategy does, however, not require backward integration into the numerical control unit production for technological (innovative) reasons. For reasons of cost efficiency, backward integration may be interesting although it should be noted that Mori Seiki, the largest producer in the world, still buys its units from Fanuc.

The main barriers to entry into this group is 1) economies of scale; 2) access to large marketing networks and 3) design skills including electronic design skills.

1. Economies of scale

It has been estimated (Jacobsson 1986) that large scale producers of CNC lathes only (approximately 2,000 units per year) could achieve a unit cost which was approximately 40 per cent lower than a small scale producer (100 units). A producer of both CNC lathes and machining centres can however benefit from some economies of scope in both procurement, design, production and marketing, thus somewhat extending the scale economies calculated by Jacobsson (1986). For example, the electronic hardware and software for the CNC units are very similar for CNC lathes and machining centres. The unit cost advantages by the leading firms (which produce approximately 4,000 units per year) vis a vis new entrants are therefore very substantial.

2. Access to a large marketing network

Selling numerically controlled machine tools is a marketing and service intensive business. Independent distributors dominate this part of the business due to significant economies of scale in these functions. As the distributors normally do not sell directly competing brands, access to selling outlets is not necessarily easy to get. This is especially true for new entrants which require extra efforts (and costs) for marketing. At the same time, firms belonging to this strategic group needs access to distributors across the entire markets in a number of large countries in order to be able to sell enough machines to realize the required benefits of economies of scale and scope in procurement, design and production.

3. Design skills

The required 'mass' of skills is substantial. The leading firms in this strategic group have between 150 to 275 design engineers, although the high figure includes electronic engineers designing the numerical control unit.

It is of course possible to pursue other strategies than the overall cost leadership strategy. Some firms focus on the demand from a range of customers across the engineering industry who need higher performance machines and who are prepared to pay a price premium for this performance. Frequently, these firms demand smaller systems too, in particular FMMs and FMCs (see section 2.3). It would appear that, so far, firms pursuing this differentiation strategy (Porter 1980) frequently specialize in the production of either CNC lathes (e.g. Index and Traub in Germany) or in machining centres (Mandelli in Italy). In the case of Germany, none of the largest producers of CNC lathes produce machining centres nor do the largest producers of machining centres produce CNC lathes. Occasionally, however, some firms produce both types of machine tools (e.g. Matrix-Churchill in the UK). An open question is if firms in this strategic group will not have to broaden their product range to include both CNC lathes and machining centres in the future.

This strategic group have presently the following characteristics. Price is medium to high and the marketing is done both directly to customers (especially for systems) and indirectly through independent dealers. R&D is focussed on designing high performance machines in combination with standardization efforts in the form of modular design. Sometimes, special application software is developed for individual customer segments. System development is important. A medium volume of output is required. Often, the numerical control unit is designed inhouse as a part of the innovation process of the firms. Firms simply want to provide functions, e.g. automatic tool compensation, which are not included in standard systems available in the market.

The barriers to entry into this strategic group lie more in design skills, brand image (among the advanced customers) and economies of scale.

1. Design skills

In terms of quantity, the number of design engineers is less than for firms pursuing the overall cost leadership strategy but the quantity of machine models to design is generally smaller. Several of the firms employ between 50 and 135 design engineers although some firms manage with fewer engineers. However, the type of design work involved is often directed towards more complex problems, e.g. system development and very high precision machining.

2. Brand image

Many of the companies buying from this strategic group would not even consider buying from an unknown supplier. Accumulated image and de facto dependability matters a great deal. Furthermore, for system sales, direct links into larger, advanced customers are essential as these involve a great deal of communication between the buyer and the seller. Such links are very time consuming (and costly) to develop and involve a great deal of trust by the buyer vis a vis the supplier.

3. Economies of scale

Although the customers of this group of firms are prepared to pay a premium for a higher performance, this willingness has a limit. Consequently, some economies of scale need to be reaped by members of this group too. Two German CNC lathe producers have reached a production of 500-600 units per year whilst others produce less. This is especially so for machining centre producers.

The firms operating in these two strategic groups account for the vast majority of the production of CNC lathes and machining centres in the OECD community. Apart from these, there are firms focussing on the production of very special machine tools, such as very large machining centres or firms basing their existence on custom designed machines for a local or regional markets.

5.3.3. A note on the structure of the CNC grinding machine industry

As was noted in section 2.2, the diffusion process of CNC grinding machines has, so far, been very different from that of CNC lathes and machining centres. It is only recently that CNC grinding machines have begun to be diffused in a significant way (see table 4).

The tremendous advances made by Japanese producers in CNC lathes and machining centres have <u>not</u> been repeated for CNC grinding machines. As can be seen in table 18, it is the German industry which is the strongest one. Apparently, the large volume markets which characterize the CNC lathe and machining centre markets have not yet materialized. In 1987, total production (in the countries listed in table 18) amounted to only 4,253 CNC grinding machines and 31,668 conventional grinding machines. In part, and as was mentioned above, this has probably been due to a nonavailability from specialized CNC producers of a system well adapted to grinding. Preliminary interviews suggest, however, that standard and cheap CNC units adapted to the grinding technology are now available and it would appear as if a volume market might be in the process of being formed now.

What a development of volume markets might imply can only be the object of speculation. From table 18, we can calculate that a bit over one third of the production of grinding machines consisted of CNC grinding machines in 1987. The share of CNC grinding machines is therefore the same as that of CNC lathes in 1977 (see table 2). As an arithmetic example, one can assume that in the next nine years, the grinding machine industry will evolve just as the lathe industry did in the period 1977-1986. In 1997, CNC grinding machine would, thus, have 78 per cent of the (assumed constant) market for grinding machines. Assume further that the unit price of the CNC grinding machines will be forty per cent lower than today and that of conventional machines the same as today. The total market for CNC grinding machines would then amount to around 15,000. The market for conventional grinding machines would be reduced to 11,000 units. To the extent that history would repeat itself, tremendous changes would be awaiting the industry.

One should, of course, be very careful in drawing too large parallells with the development of other industries, but a closer look at the grinding machine industry would clearly seem worthwhile.

Table 18

The production of conventional and CNC grinding machines in some OECD countries and Korea in 1987 (in units and million USD)

	Conventional		CNC	
	Units	value	Units	value
FRG	13,795	305	2,459	405
USA*	6,955	369	765	136
Japan	7,352	412	939	132
Italy	1,345**	128	75	30
Korea	2,241	24	15	1
Total	31,688	1,238	4,253	704

* Exc.'uding machines with a unit price of below USD 2,500
** Including those without NC specification

Sources: Data recieved from CECIMO and NMTBA (1988/89)

6. Implicatiors for qovernment policy

In this final section, we will discuss implications for government policy of the 'revolution' which we have described above. We will begin by discussing the problem of adoption of NCMTs in the developing countries and then proceed to discuss issue of a local supply capability in NCMTs in the developing countries.

6.1 Government policy vis a vis local adoption of NCMTs

The present level and rate of diffusion of NCMTs is substantially less in the NICs (and by assumption in the rest of the developing countries) than in the developed countries. One possible reason for this slower rate of diffusion could be the product mix where Boon (1985:40) argues that is ~~is~~ such that the potential for applying NCMTs is less than in the industrially advanced countries. Whilst this might well be true to some extent, there are also factors which would suggest that the present level and rate of diffusion is substantially below its potential. There is quite a a lot of evidence (Edquist and Jacobsson 1988: chs 9 and 12) for suggesting that there is a lack of information about NCMTs and a lack of knowledge of how to use and repair and maintain them, especially in the small and medium sized firms. In addition, in many NICs, the price of NCMTs is very high in relation to both the price of labour and the price of conventional machine tools. This reduces the scope for profitable application of NCMTs. ~~In Figure 1, X1 would move to the right and X2 to the left.~~

The high local prices of NCMTs ~~is~~ are to some extent due to the industrial policies which foster the local production of machine tools. This has led to a higher self sufficiency ratio in terms of NCMTs in, for example, Argentina, Brazil and Korea, than in the US and in the UK. This high self sufficiency ratio (combined with a small production) can lead not only to high unit costs but also to a lack of choice for the local customers as regards the precise performance characteristics of the NCMTs. A central feature in the global NCMT industry is clearly the wide differentiation of its products. CNC lathes and machining centres, and other NCMTs, are sold in many different sizes, with greatly different performance and with different degrees of standardization. Clearly, no local industry, not even the Japanese, can supply the local industry with all types of NCMTs. A very high local self sufficiency ratio in some NICs might therefore imply that the potential users in the NICs may have to be satisfied with a more narrow choice of sizes and models than their OECD counterparts. Thus, access to some version might be limited to the NIC firms and this might then lead to a non adoption decision.

Thus, there are good reasons for suggesting that the potential for diffusion of NCMTs is much greater than the actual diffusion. A government policy could therefore be aimed at removing the obstacles for a faster diffusion. As far as information is concerned, a number of developing countries, e.g. India, Korea and Tawian, have set up national institutes which have a a function to diffuse information about new technology. Apart from such activities, one might suggest that the experiences of the developed countries in subsidizing industrial 'show cases' could be evaluated. In this way, the government may subsidize the investment in a private firm which, in return, allows representatives from other firms to closely study and learn from their investment.

As far as knowledge and skills are concerned, this is basically a question of the proper functioning of the educational system. We would emphasize that the technical training schools must reorient their curricula so that relevant human skills are available. This means that less emphasis should be given to the education of traditional machine tool operators and more to educating operators of NCMTs and to the associated programming, setting and maintenance staff. In short, a limited number of engineers and technicians with a knowledge in both mechanical engineering and electronics should be educated instead of a considerably larger number of skilled operators of conventional machine tools.

When it comes to prices of NCMTs and to the access to a wide range of models etc, this is an important aspect of the decision about how (and if) a local supply capability should be supported. This will be discussed in section 6.2.

Although we do believe that the present diffusion of NCMTs is slower than optimal in the NICs, the potential level of diffusion is most probably lower than in the developed countries, simply on account of different relative factor prices. The reduction in the supply capacity for conventional machine tools in the OECD countries (see tables 1-4) might therefore be looked upon as problematic for future investors in conventional machine tools. However, the supply of such machine tools in the NICs is very great indeed. In Korea and Taiwan, Republic of China, only 20 per cent of the production of machine tools was in the form of NCMTs in 1986. Even in these countries, the transformation to NCMTs is a slow one. Large production capacity in conventional machine tools also exists in China, India and Brazil too. Access to conventional machine tools will probably not be a problem, not even in the long term.

6.2 Government policy vis a vis a local supply capability

There is a considerable production of NCMTs in the NICs, including China. The largest producers are Taiwan, Province of China with a production of 1,917 units in 1986 (Korea Machine Tool Manufacturers' Association 1987:491); Korea with a production of 1,124 (Korea Machine Tool Manufacturers' Association (1988:123) and Brazil with a production of 710 units in 1986 (Fleury 1988). India produced 193 units in 1987 (CECIMO 1988). Most, if not all of these countries foster their machine tool industry, often due to an alleged 'strategic importance of this industry. In this final section of the paper, we will very briefly adress the question of government policy vis a vis the local machine tool industry. Detailed policy prescriptions are not made but the discussion seeks to identify two different roles for the local machine tool industry which, in turn has a bearing on government policy.

It is, indeed, often claimed that the machine tool sector is a strategic sector (also by analysts in the developed countries). The basis for this allegation is that the industry provides the entire metalworking industry with its key process technology. From this observation, which is true, it is however often, and probably wrongly, concluded that the domestic machine tool sector is strategic.

As in the metalworking industry itself, there is a very considerable international trade in machine tools. This was shown in tables 10 and 11. As long as the development strategy of the country as a whole does not rely greatly on trade restrictions, the amount of machine tools that the local metalworking industry sources locally tends to be small and decreasing, chiefly on account of the benefits of specialization that exists in the industry (Jacobsson 1988). The local machine tool industry, in turn, relies to a growing extent on the external market as an outlet for its sales. Hence, the domestic machine tool industry can not, on the whole, be seen as strategic in the sense of being a transmitter of new technology to the local engineering industry. In todays world, it is therefore the global machine tool sector which act as a global transmitter of new technology to the global metalworking industry.

To the extent that the development strategy aims at an integration with the world economy, the government policy (if there is to be one) for the machine tool sector should therefore aim at fostering internationally competitive firms which eventually will end up as full scale participants in one of the strategic groups outlined in section 5. At the same time, the instruments of intervention should be chosen so as not to reduce the scope for choice for the local metalworking industry as regards different variants of machine tools.

The Taiwanese example is a very powerful one where a specialization on simpler machine tools (both NCMTs and conventional) sold to customers in mainly the developed countries (chiefly to North America) has made Taiwan into the 15 largest producer of machine tools in the world and to the 11th largest exporter in 1986 (NMTBA: 1988/89:16). On the whole, the Taiwanese government has intervened relatively little (Jacobsson 1986) and used conventional industrial policies using instruments such as credit policies. It is important to note that it has not greatly limited the import of machine tools or raised the price of imported machine tools, something which could have a strong negative effect on the international competitiveness of the local engineering industry.

Whilst the Taiwanese example shows the large benefits that can be reaped from an international specialization in the machine tool industry, it is important to note that it is still not a full scale member of the overall cost leadership strategic group for machining centres and CNC lathes (which its main firms are aiming to be part of). The entire Taiwanese production of NCMTs amounted to less than 2,000 units in 1986 which is only half of the production of one of the four largest Japanese producers (see table 17). In addition, as was mentioned above, the US has imposed 'volontary' export restrictions at a fairly low level (400 machines annually) which does reduce the growth potential of the Taiwanese firms. Obviously, the high barriers to entry and the existence of trade barriers make it very risky to aim for the eventual pursuit of the overall cost leadership strategy for new entrants in the CNC lathe and machining centre business.

In an economy which follows an inward looking industrialization strategy, like India and China, the situation is entirely different. The domestic machine tool sector takes here on the extremely important role of a transmitter of new technology all by itself. The behaviour of the local machine tool sector is therefore a key factor determining the level of productivity in the local metal working industry. This implies that when discussing the appropriate government policies, it is chiefly the local users' viewpoint that need to be taken. As indicated in section 6.1, what matters here is not only how cost efficient the machine tool industry is but how well it makes available to the local customers the technology which is state of the art in the global industry.

As was mentioned above, there is no local machine tool sector in the world which has a breadth in its product technology which satisfies the demand from the entire local metalworking industry. Imported technology is therefore required to keep the local metal working industry up to date in production technology. The pressure to rely on imported technology, be it embodied in products or through licensing agreements, would, of course, tend to be greater the smaller the local machine tool industry is. To the extent that imports of embodied technology is prohibited (as it tends to be in inward looking economies), the obvious conclusion is that to ensure a diversity of choice for the local engineering industry, multiple foreign technological collaborations need to occur. Hence, in an inward looking industry which wants to have access to the latest varieties of the new technology, the a prime government instrument would be a liberal technology import policy.

The Indian experience for machining centres might be illustrative here. Up until the early 1980s, India had a very restrictive technology import policy. At the same time, it was difficult to get a government permission to set up production of a new product if there were already producers in the same, broad, field. As a consequence, there was only one producer of machining centres offering only a very limited range of models to the Indian engineering sector. The diffusion of machining centres was slow.

In the early 1980s, there was a considerable liberalization of the industrial policy framework although the basic inward looking development strategy was kept (Jacobsson 1988a). Instead of one producer of machining centres, there were eight which had licence agreements with the leading machining centre producers in the world. The liberalized policy framework thus ensured that the Indian engineering industry had access to a great variety of machining centres (although not as great as under a free trade regime). The diffusion of machining centres has now picked up significantly.

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