UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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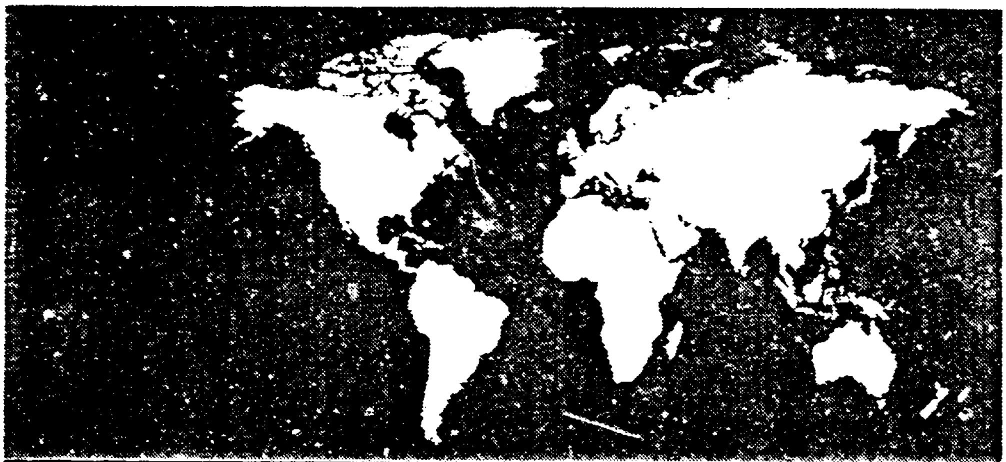

Background Paper

The impact of industrial automation on industrial organization: Implications for developing countries' competitiveness

Prepared by

LUDOVICO ALCORTA

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

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This study was prepared by Ludovico Alcorta of the United Nations University Institute for New Technologies (UNU/INTECH), Maastricht, the Netherlands, as consultant.

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I. INTRODUCTION

During the eighties emerged a profuse literature pointing at a number of potential advantages of recent microelectronics-based industrial automation for developing countries. It was claimed that industrial automation was leading to fundamental changes in production organisation, optimal scales of output and economies of scope, vertical integration and the relationship between large and small firms that would generally be favourable to developing countries. Old forms of production organisation such as mass production would be replaced by new ones characterised by flexible production based on general purpose machinery and skilled and semi-skiled workers. Optimal scales of output would fall while at the same time it would be economically feasible to produce a wide variety of goods. Large firms would decentralise a significant proportion of their production activities leading to vertical disintegration. Such changes in industrial organisation open opportunities for developing country industrial development. Developing countries industrialisation had always been limited by high capital requirements, increasing optimal scales, excessive diversification and vertical integration and inefficient small scale production.

The purpose of this paper is to examine these claims in the light of trends in diffusion of industrial automation and on the basis of an increasing amount of empirical research on the impact of industrial automation on industrial structure. It will argue that contrary to early expectations, industrial automation does not seem to be leading to the beneficial effects expected by early predictions in the literature. It will point out that while diffusion of new technologies has proceded at a rapid pace in developed countries, this has not been the case in developing countries. It will suggest, on the basis of an exhaustive analysis of the mechanical engineering industry, that industrial automation may lead to less production flexibility, higher optimal scales of output, increasing vertical integration and increasing research and development effort. These effects should make it more difficult rather than easier the process of industrial development for developing countries. However, it also argues that developing countries have little choice but to adopt the new technologies if they are to have any chance of engaging in a sustained process of industrialisation and technical change.

The paper is structured in five sections. It begins with an historical account of the process of development of industrial automation and the role of microelectronics. Second, it analyses trends of diffusion in industrial automation in developed an developing countries. Third, it examines the impact of industrial automation in variables of industrial structure such as production organisation, economies of scale and scope, vertical integration and research and development requirements. Fourth, it analyses the implications of changes in industrial structure for developing countries and, finally, it presents some concluding remarks.

II. MICROELECTRONICS AND INDUSTRIAL AUTOMATION.

With the industrial revolution began a systematic and sustained quest to substitute machines for human effort. Triggered by the combination of advances in classical mechanics, the invention of the steam engine, improvements in the getting and working of raw materials and by increasing division and specialisation of labour, the industrial revolution became the turning point from handicraft to manufacture (Giedion, 1948; Landes, 1969; Smith, 1970). Classical mechanics provided the understanding of the motion of bodies under the action of forces and led to the development of mechanical engineering. The steam engine became a continuous source of power. Better methods of extracting and producing raw materials provided increasing volumes of cheap inputs and energy. Division and specialisation of labour resulted in the factory form of industrial organisation. The underlying factors leading to this transition were scientific curiosity, technical inventiveness and, paraphrasing Adam Smith, "the propensity to truck, barter, and exchange one thing for another" (1970, pg. 117).

The first phase in this, simultaneously liberating and self-destructing, human endeavour was the development of machines, ie. devices replacing human or animal power with mechanical power for the accomplishment of physical tasks. Since the appearance of the first steam engine around the mid of the eighteenth century, powered engines and machines were devised that obtained their energy from steam, electricity, and chemical, mechanical and nuclear sources. Whatever the source of power, all machines that were developed had an input, an output, and a transforming or modifying and transmitting gadget.

Earlier machines maintained unvarying connections between their parts while foreclosing all other unnecessary actions, in order that the same action could be repeated over and over again, according to a pre-established routine and with precise timing. The mechanisms were designed in such a way that they simultaneously transmitted power, transformed motion and controlled the speed and direction of movement. Unlike humans, machines could not react to changes in input conditions nor to errors or differences arising during their operation. Growing mechanisation exposed, therefore, the problem of the control mechanism to harness the power of machines. The first steam engines needed a person to open and close the valves admitting and exhausting the steam into the piston chamber. Once a device was inserted to carry out this task, a person was required to regulate the amount of steam in order to achieve the desired speed and power. Only after the introduction of Watt's flyball governor, which controlled the valve regulating the amount of steam through a weighted ball which began to move outwards as the speed of the output shaft of the engine increased, was the need for a human operator eliminated.

Between the introduction of the flyball governor in the late 1780s and the beginning of the nineteenth century, a number of innovations in controls emerged. In textiles, the Jacquard attachment, a shedding device which attached to a loom was capable of producing complex patterns in textiles by controlling the motions of threads without the support of an assistant or 'drawboy', was developed. In machine tools the slide rest or tracer technique was added to lathes. The slide rest, sitting at the base of the lathe, was a template that controlled the feed rate and the movement of the tool, making the presence of a worker to shape the workpiece to the desired pattern redundant. Also the stocking lathe for the shaping of gunstocks, which for the first time included a cam, was introduced. By conveying its shape or some transformation of its shape to a tool linked to a follower or workpiece, the cam functions de facto as a blueprint for shaping the workpiece. Cams are particularly useful for reproducing irregular patterns and have the added advantage that a wide range of motions and shapes can be produced without rebuilding the machine each time a new design is used. In addition, electric power and the portable electric motor, made it possible to control different parts of machines at different speeds without being connected to the same primary power source and hence avoiding long transmission trains.

Despite these and other advances in control devices, machines were still not capable of dealing with the problems of variability in input conditions or processing errors that human beings can. Cams and tracer techniques were always limited by their design and had to be replaced with every new shape. Furthermore, cams were both the control and the transmission system as they provided the guide to control the tool and the force to move it, therefore requiring metallic thickness and mass and accurate contour. This was expensive because of the technical difficulties to achieve it. The flyball governor was an ingenious feedback-based control system because the increase in output of the engine was used to decrease its activity. Yet, according to Hirschhorn (1984), it remained an 'intuitively' developed mechanical extension of the engine and valve, which did not 'sense' changes in conditions independently nor had been understood sufficiently to identify the principles of feedback control.

Thus, a second phase in the replacement of human effort by machines began to emerge around the early twentieth century with the development of industrial automation. Unlike mechanisation, industrial automation not only involves the replacement of physical effort by machines but entails the displacement of some of the decision making capabilities of the operator.[1] It is based on the concept of feedback control which consists of a procedure of measuring and inspecting or 'sensing', the evaluation and processing of this information in relation to a theory or algorythm of the process, and an output of instructions as a response if required (Kaplinsky, 1984; Ramtin, 1991). Feedback control allows for the development of more flexible machines and production processes.

The foundations of industrial automation need to be traced to the development of quantum mechanics, which deals with atoms and molecules, electronics, which studies the motion of the electron, and process control theory, which describes the behaviour of output variables as a function of adjustable and non-adjustable variables and time. Also inventions such as the vacuum tube, the transistor, the integrated circuit and the microprocessor, which led to the emergence of microelectronics, and a wide variety of new sensing devices were essential to the progress of industrial automation. Quantum mechanics and electronics provided an explanation for the nature and behaviour of particles and electromagnetic waves of atomic or sub-atomic size and the way in which the motion of the electron could be utilised. Process control theory provided knowledge on the principles of control i.e. feedback and feed forward, on the ways of implementing these principles, and on the mathematical models to represent processes. Microelectronics, i.e. electronic units using very small solid state components, provided devices for storing, processing and computing information that were notably smaller and diminishing in size, of an exceedingly high and increasing speed and reliabilty, and of very low and decreasing costs (Dosi, 1984; Soete and Dosi, 1983). Indeed, by reducing the price-performance ratio of control devices by 'several orders of magnitude', microelectronics became the basis for revolutionary advances in industrial automation (Freeman, 1982).

Contrary to popular belief, and perhaps also to conventional academic wisdom, automation did not develop first in batch industries. It is often argued that earlier transfer machines and moving machining and assembly lines are the archetypes of automation or, more precisely, 'fixed automation', because they involve transforming components which were fed at one end and emerged at the other end as fully machined or assembled products without human intervention (Kaplinsky, 1984; for early and more recent reviews of automation see Bell, 1972; Morroni, 1992; Ramtin, 1991). However, to the extent that transfer machines and moving machining and assembly lines were not based on

[1] In the early literature on automation, mechanisation was concerned with the replacement of human physical effort while automation with the replacement of human mental effort (for a discussion see Kaplinsky, 1984; Ramtin, 1991).

feedback control, intricate as they were, they remained essentially machines or groups of machines linked by a mechanical transportation system.[2] The extent of the difficulties in keeping up with work in moving assembly lines because of their uncontrolled pace was graphically described in Chaplin's Modern Times film, and less seriously but equally compelling, in more recent TV cartoons.

To be sure, it was in process industries such as the petroleum, chemical, steel, cement and food industries where early advances in automation were made. Take the case of petroleum refining according to the accounts of Freeman (1982) and Hirschhorn (1984). Up to the World War I petroleum refining essentially consisted of a crude distillation process in open vessels in which the oil was heated and vaporised fractions separately condensed. Under pressure from the automobile industry for cheaper and more efficient fuel, the industry's three major changes took place in the following twenty years. First, the development of tubular heaters in which the oil passed continuously and rapidly at higher pressures and temperatures through pipes in a furnace, leading to the splitting or cracking of molecules. Second, the attaching of fractioning towers which redistilled lighter components through another tubular heating process. Third, the introduction of chemical catalysts to speed up the cracking process. Because separate processes such as distilling, fractioning and cracking were being increasingly integrated into a single continuous process, the problems of potential disruption from each other and of overall regulation began to arise. This, in turn, required controls that would operate at the same rate as the chemical and separation processes that were taking place, leaving no room for direct human intervention.

Initially, controls in process industries were rudimentary and worked on electrical, pneumatic, and hydraulic principles. Electrical and some primitive electronic control devices were not favoured at first because of risks of fire and explosion. Sensing gadgets included thermometers, tachometers, thermostats and float balls. Early controls and sensors operated on specific parts of the process but between the 1930s-1950s, as short distance communication techniques improved and because of the increasing use of relays, controls were progressively linked, first, into local stations and, finally, into a central control room.

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[2]The quantitative importance of these machines has also been put into question. The Economic Commission for Europe (1986) reports that production under 'rigid mechanisation' conditions in the mechanical engineering industry never exceeded more than 25% of total output. Jacobsson, on the basis of American Machinist data, estimates that only 0.8% of the total stock of metal cutting machine tools were station type machines, including transfer lines. Only 5% of plants had such machines. Around 36% of transfer lines were in the transport machinery industry (personal communication). Hirschhorn (1984) estimates that around 10% of total industrial labour force was involved in assembly, not all of them in moving assembly lines.

The introduction of digital computers in the 1960s offered the possibility of breaking away from previous unreliable electromechanical controls and move into faster, reliable and more accurate devices, capable of data storing and processing and of performing a series of complex mathematical operations. But, by and large, early computers were a failure in process industries because of constant breakdowns due to their sensitivity to the external environment, leading to expensive back-up measures and difficulties in developing models and writing programmes that took all intervening variables into account (Hagedoorn, 1989; Hagedoorn, Kalff and Korpel, 1988; Hirschhorn, 1984).[3] This situation changed drastically with the advent of microelectronics. Since 1975, devices such as programmable logic controllers, micro and process computers have been developed. Together with appropriate software and novel measuring instrumentation, also microelectronics based, the new control devices are simultaneously capable of data gathering, processing and storing, computing, regulating, controlling, interfacing with the operator and communicating with other devices and outside the system with or without human intervention.

Automation of batch industries had always proved to be more difficult than that of process industries because of the frequent and strong deviations from the steady state situation during the starting-up, operating and stopping of procedures (Hagedoorn, Kalff and Korpel, 1988). Consider the case of mechanical engineering, and specifically of metal cutting activities. Until World War II metal cutting was done through lathes of different sorts and general purpose or conventional drilling and milling machines. There were also special-purpose, machines, such as gear-cutting or boring machines. Finally, there were specially-designed machines, like the transfer machine, which was divided into a series of workstations, each station performing one or a combination of machining operations and connected by a parts handling and moving system. Irregular shapes were normally cut by a machinist in general purpose machines by cutting closely spaced holes along a path that followed the desired contour. As Reintjes (1991) notes, this approach, using a discrete-positioning technique for an operation that obviously required continuous cutting, was 'expensive' because it required stopping and resetting the machine every time a new hole was to be cut.

Automatic continuous cutting along a straight line required the combined accurate positioning of the tool and workpiece along three dimensions. This involved a complex set of movements the commands for which, it was believed at the time, could be conveyed to the motor of the machine tool

[3] Between 1963 and 1971 eighteen process-control computers were installed in cement factories in the US. Three computers failed altogether and two were returned to vendors. The other fifteen had a very uneven performance (Hirschhorn, 1984).

through a device or 'servomechanism' which created digital signals corresponding to numbers. These signals were then compared with signals arising from the actual position of the tool and workpiece prompting corrective action if necessary. The 'numbers' or 'commands' were to be contained in punched cards or magnetic tapes. With financial support of the US Air Force, Parsons Corporation, an aircraft subcontractor, and the Massachussetts Institute of Technology (MIT) teamed up in 1949 to develop such machine. By 1952 the first numerically controlled machine tool was produced. Numerically controlled machine tools were a significant breakthrough because it was no longer necessary that the structure of a machine be modified to adjust for a new product.

Between 1960 and the late 1970s numerically controlled machine tools and early-computer controlled machine tools diffused throughout mechanical engineering. Yet, they faced the same problems that had hindered the use of early computer controls in process industries, namely, expense, unreliability and 'user unfriendliness', and did not displace previous machine tools significantly. Again, as in process industries, it was only after the emergence of microelectronics that computer controlled machine tools became both a viable technical and economic alternative for industry.

Since the late 1970s microelectronics has led to the accelerated development, refinement and diffusion of a number of new devices and machine tools for the mechanical engineering industry. This includes computer numerical control (CNC) machine tools, such as lathes or machining centres; industrial robots, i.e. reprogrammable multipurpose manipulators; computer aided design/engineering (CAD/CAE), which allows graphic representation and electronic drawing, and generates engineering data and programmes for modelling products; computer aided manufacturing (CAM), i.e. the combination of CNC machine tools with the monitoring and control of production process, especially the flow of material; automated guided vehicles (AGV), i.e. unmanned electronically driven vehicles for transport of workparts and material; automated storage and retrieval (AS/AR), i.e. electronically controlled handling and storing devices; flexible manufacturing systems (FMS), combining robots, CNC machine tools, AGVs, AS/ARs and central computer control which coordinates all steps of production.

The new technologies have a number of characteristics that make them a major breakthrough for the mechanical engineering industry. First, is the 'flexibility' they have introduced into the production process. Production flexibility is defined by this literature in terms of the capacity to switch rapidly to the production of a far wider scope of goods than before (Carlsson, 1989a; Morroni, 1991). It is the result of the equipment's capacity to be programmed in different ways and therefore vary in its response accordingly.

A second characteristic of NT is their ability to integrate different pieces of equipment (Bessant, 1991). Microprocessors' and computers' capacity to handle large amounts of information allows a far more precise and hierarchical, while at the same time adaptable, control of individual pieces of equipment and of the whole production process. Better control capabilities, in turn, facilitate the integration of more mechanical functions into individual machines, of machines into more complex production systems, and between them with other business functions. The machining centre, for instance, integrates drilling, milling and boring operations, which used to be done in separate machines, into a single machine.

A third characteristic of the NT is their speed and precision. Microprocessor control of motor and spindle speeds allows for faster acceleration and deceleration (Twiss, 1981). In CNC machine tools all the hard-wired circuitry is replaced by chips, increasing even further operating speeds. Computers' capacity to deal with considerable information also allows to define co-ordinates and angles more accurately and to operate within finer tolerance margins. The machining centre, for instance, was first introduced in 1958 following the introduction of numerical control. In early machines, power transmission was done on the basis of several cams, gears and shafts, and they could only handle three operating positions and around twelve tools. Although the basic design of the machine has not changed since, a machining centre today is electronically controlled, does not require a complex power transmission mechanism, can operate in most angles and at faster speeds and can handle hundreds of tools.

In sum, it has been argued in this section that the quest to substitute machines for human effort has had two cumulative phases. A first phase or 'machinofacture', where the key characteristic was the replacement of human physical effort and which lasted from the industrial revolution in the mid of the eighteenth century to the beginning of the twentieth century. The second phase, industrial automation, aimed also at replacing some of the decision making capabilities of the operator on the basis of self-operating feedback control, began around the 1920s in continuous process industries and spread to batch industries in the 1960s. Yet, industrial automation only became technically and economically viable once microelectronics and microelectronics-based technologies developed.

III. WORLD DIFFUSION OF INDUSTRIAL AUTOMATION.

Because of the emphasis on feedback control as the defining factor, industrial automation includes a wide variety of self-regulating equipment which is in use in almost any industry. It also includes any combination of machines which are jointly controlled from a computer. And, it possibly consists of parts of plants or even whole factories which are completely unmanned and computer controlled, although 'factories of the future' still seem to be a long way away. The upshot is that it is extremely difficult to obtain precise figures for international diffusion of industrial automation as there is no single source of supply of automated equipment and, therefore, of information. Plant surveys are extremely useful because they provide insights into the type of equipment and controls being used, but they are not done everywhere nor they are generally comparable. This leaves the analyst with no choice but to combine data from different sources and make a judgement on the possible overall trends by country.

3.1 Industrial controls.

Perhaps the best place to start with is data on the diffusion of automatic controls. Inasmuch as automated equipment requires automatic control, data on the use of industrial control and instrumentation should provide an idea of the level of use by different countries.

Table 1 provides an idea of apparent consumption, i.e. production plus imports minus exports, of industrial control electronic equipment for 1993. Industrial and process control includes complete automatic regulators or controlling apparatus both for process and batch industries, process control instruments include implements for measuring pressure, flow and level, industrial equipment includes signalling equipment of diverse types, active components include all types of cathode ray tubes and integrated circuits, and passive components include capacitors and resistors, relays, switches and printed circuit boards. More than half of active component production is microprocessors or 'chips' of different type, most of which are not necessarily used in industrial automation, though there is no way of determining how much is.

TABLE 1: APPARENT CONSUMPTION OF INDUSTRIAL ELECTRONIC CONTROL EQUIPMENT IN 1993 (US$ MILLION)

	TOTAL ELECTRONIC EQUIPMENT[1]	Industrial Control Electronic Equipment								
		Control and Instrumentation				Medical and Industrial		Components		
		Total	Of Which: Industrial and Process Control	Of Which: Instruments	Of Which: Accessories and Parts	Total	Of Which: Industrial	Total	Of Which: Active	Of Which: Passive
TOTAL	738098	64869				27768	8729	198498	108346	55368
1.Developed Countries	607527	53381	19747	27266	3908	23254	7821	153543	84730	41820
a. Western Europe	196857	21716	8781	10016	2917	7210	3514	40454	17169	13577
b. North America	66400	24994				10998	3339	63856	38788	15249
c. Far East	144270	6671				5046	968	49233	28773	12994
2.Eastern Europe[2]	15321	2593	na	na	na	868		2693		
3.Developing Countries	115250	8895	na	na	na	3646	1326	42262	23616	13548
a. Asia	82563	6194				2120	908	35204	[illegible]	11335
b. Latin America	23843	1850					217	5556	2531	1513
c. Africa & Middle East	8844	851					201	1502	1065	700

[1] Includes electronic data processing, office equipment, control and instrumentation, medical and industrial, communication and radar, telecommunications, consumer and components.

[2] Estimated.

Source: Elsevier's Yearbook of World Electronics Data 1993, 1994, and 1995.

A number of points arise regarding this table. First, industrial control electronic equipment accounts for anything between 10% and 37% of total electronic equipment apparent consumption. As probably only a small share of components is used in automated equipment the actual figure is likely to be near the lower bound estimate. Considering only control and instrumentation, industrial electronic equipment, and on the assumption that only 10% of components find their way into automated equipment, the market for industrial electronic control would have been around US$94 bn in 1993, or 12.7% of total electronic equipment.

Second, developing countries have a share of only 13.7% of the control and instrumentation market and 13.1% of the industrial equipment, lower than their 15.6% share of the total electronic equipment market. Arguably, the industrial and process control equipment industry is among the most science-based within the electronics industry because of its higher research and development intensity (R&D) and patenting activity, emphasis on basic and applied research as opposed to product development, and having a larger share of innovations that are used and produced by itself and used by other industries (Hagendoorn, 1989; Pavitt, 1984). This suggests that developing countries' share in total consumption of industrial automation may not only be low but also biased towards less advanced electronic products. Furthermore, the relatively large share in active components is partly accounted by a high proportion of cathode ray tubes, which apart from being industrial 'commodities', i.e. low value added goods whose price is determined in the world market under very competitive conditions, are mainly used in consumer goods. While some of these tubes may be finding their way into exports, the fact that developing countries also account for around 27% of the total consumer electronics goods market also hints at a strong preference for consumer electronics in these countries.

Third, use of industrial automation seems to be heavily concentrated in a few developing countries. China, South Korea and Brazil account for 47.6% of total purchases of control and instrumentation and 43% of total industrial equipment (see Appendix 1 for details). China, South Korea and Taiwan account for 50.5% of total active component production, although most of Chinese consumption is cathode ray tubes which are of little use for automation, while that of Taiwan and South Korea is integrated circuits. Consumption of passive components is more evenly distributed among developing countries but these components tend to be among the less sophisticated components.

On the whole, the data suggests that developing countries are relatively minor users of electronic control technology. That their demand is directed not so much towards control technology but rather to low-knowledge, low-value added products and to consumer electronics. And, that what little use of electronic control technology there is, it is heavily concentrated in a few countries, namely South Korea, Taiwan and Brazil.

3.2 Metal-cutting machine tools.

So far we have been discussing the diffusion of electronic control technology in a single year. However, this says nothing of the long run trends in the use of industrial controls nor does it say much about the diffusion of equipment that uses automatic control. Given that the strongest impact of industrial automation is said to be found in mechanical engineering, and within it in metal cutting activities, we will turn our attention to the discussion of the diffusion of machine tools.

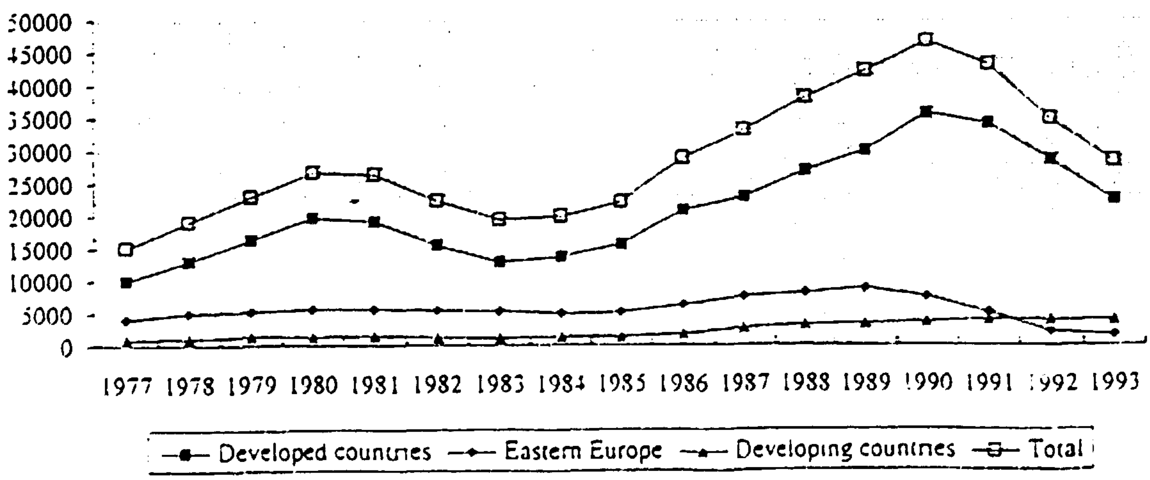
Since the introduction of numerically controlled machine tools in the 1960s, but more significantly, since the arrival of CNC machine tools in the mid seventies, rapid diffusion of these technologies has taken place. Between 1977 and 1993 production of machine tools grew at an annual cumulative rate of 6.2%. Developed and developing countries' machine tool production rate was higher than the average, compensating for the relatively low growth rates of Eastern European countries (Table 2). Developed countries' high growth rate was partly the result of the emergence of highly export-oriented machine tool industries in Japan and, up to 1990, Switzerland. Developing countries' rate is explained by the performance of the also export-oriented Korean and Taiwanese machine tool industries (for an account of the experiences of these industries see Jacobsson, 1985; Amsden, 1977, Judet, 1991). Machine tool production growth rates would have been much higher had it not been for the acute recession facing developed countries between 1990-1993 and the demise of former communist countries.

TABLE 2: WORLD MACHINE TOOL PRODUCTION, 1977-93
(millions of US$)

	Machine Tool Production (US$ mn)					Structure of Production by Country (%)					Growth Rate of Machine Tool Production (% annual average)					
	1977	1981	1986	1990	1993	1977	1981	1986	1990	1993	77-81	82-86	87-90	91-93	77-90	77-93
World	15110	26353	28775	46588	28249	100	100	100	100	100	12.3	1.1	8.0	-12.0	7.0	6.2
Developed Countries	10065	19154	20791	35513	22433	66.6	72.7	72.3	76.2	79.4	14.3	1.3	9.7	-11.3	7.7	7.1
Western Europe	5933	8907	10922	21156	11647	39.3	33.8	38.0	45.4	41.2	11.2	1.6	8.8	-11.9	6.8	6.4
North America	2512	5380	2957	3509	3615	16.6	20.4	10.3	7.5	12.8	15.5	-9.3	5.5	-0.3	2.6	2.4
Far East	1620	4867	6912	10848	7171	10.7	18.5	24.0	23.3	25.4	21.0	8.4	13.1	-14.6	13.9	12.5
Eastern Europe	4131	5659	6228	7475	1680	27.3	21.5	21.6	16.0	5.9	7.2	0.0	2.0	-36.1	4.7	1.4
Developing Countries	914	1540	1756	3600	4136	6.0	5.8	6.1	7.7	14.6	10.7	3.2	7.3	0.8	8.4	8.8
Asia	565	1176	1369	3080	3758	3.7	4.5	4.8	6.6	13.3	14.6	3.1	10.3	1.4	11.2	11.4
Latin America	349	364	387	510	377	2.3	1.4	1.3	1.1	1.3	2.5	2.6	-5.1	-2.7	0.8	0.7
Africa				10	1					0.0				-7.1		-13.2

Source. American Machinist.

World machine tool production, 1977-93
(millions of US$)



As far as the structure of production (Table 2) and demand (Table 3) is concerned, both developed and developing countries increased their share in total output and consumption at the expense of the Eastern European industry (see also Appendices 2 and 3). The former USSR machine tool industry more than halved between 1990 and 1993, while the East German virtually disappeared as it was taken over by the more technologically advanced Western German industry. In 1993 there were practically no imports of machine tools in the whole of Eastern Europe. There has been a significant change in the composition of production within developed countries. Japan increased its share of output from 10.6% in 1977 to 25.3% in 1993 while the US's share fell from 16.6% in 1977 to 6.7% in 1990, recovering to 11.6% in 1993. However, Japan only accounts for around 14% of total world demand while the US for around 16%. Germany accounts for around 18% of output but demands only around 13% of the total. Within developing countries, South Korea and Taiwan increased their share of machine tool production from 0.4% to 2.2% and 3.8% respectively over the same period, although the former is a net importer while the latter is a net exporter. But more importantly, China nearly trebled its share of total machine tool output to 6.1% between 1990 and 1993. In 1993, China was the fifth largest producer of machine tools in the world and the second largest consumer, accounting for around 12% of world demand.

At first sight, the performance of developing countries production and consumption of machine tools looks impressive. On closer inspection, however, the situation does not seem to be as bright as it looks for all developing countries. To begin with, the very high growth production and consumption rates are mainly the result of growth in South Korea, Taiwan and China. If we exclude the former two countries from the production figures, developing countries' machine tool production growth rate would fall to 4.6% p.a. between 1977-1990. Except for the US, which in any case is a very large consumer of machine tools, no other developed country has experienced such low production growth rates during this period. Secondly, imports of machine tools by all developing countries, except South Korea and China, are falling. Between 1980-1988, the only years for which we have figures, imports fell at an annual cumulative rate of 1.8% (UNIDO, 1991a). Modest growth in output together with falling imports suggests that there has been little diffusion of metal cutting machine tools in most developing countries. Even in second-tier NICs, such as Thailand, Indonesia or Malaysia, the rate of growth of machine tools imports would seem to be lower than the rate of growth of apparent consumption in developed countries. Thirdly, and perhaps more importantly, the qualities of machine tools purchased by developed and developing countries may be differing markedly. The average ratio of CNC machine tools to total machine tools used in developed countries was 61% in 1991, but in countries such as Japan and Germany the ratios are over

70% (Alcorta, 1994; ECE, 1994). In developing countries, South Korea and India had equivalent ratios of 52.5% in 1992 and 26.4% in 1993 respectively (KOMMA, 1993; Rao and Deskmukh, 1994). This suggests that the difference in level of diffusion of automated equipment between developed and developing countries may be much larger than what the raw figures show.

Table 3: World Machine Tool Consumption, 1987, 1990-1993

(Millions of US$)

	1987	1990	1991	1992	1993
Total	29718	42828	39373	31451	17651
Developed Countries	19041	30124	28535	23166	17516
Western Europe	10513	17253	15222	12932	8130
North America	4675	5305	4904	4455	5398
Far East	3826	7566	8409	5779	3988
Eastern Europe	6722	7777	4903	2267	1771
Developing Countries	3982	4927	5935	6018	6364
Asia	2982	4036	4723	5149	5736
Latin America	926	765	757	821	583
Africa	74	126	455	48	45

Source: American Machinist.

In sum, although there has been significant diffusion of automated equipment in developing countries, this has been mainly concentrated in a few countries, notably China, South Korea and Taiwan. As far as industrial automation is concerned, the 'technological distance' between developed and developing countries would seem to be widening. There is no 'convergence' between countries. Thus, developing countries would also seem to be missing the second major phase in the quest to replace human effort.

IV. IMPACT OF INDUSTRIAL AUTOMATION ON INDUSTRIAL ORGANISATION: THE CASE OF THE MECHANICAL ENGINEERING INDUSTRY.

The introduction of thermal and catalytic cracking in the petroleum industry in the 1920s implied a major firm restructuring, leading to changes in production organisation, scale of operation, capital intensity, degree of vertical integration and patterns of innovation and competition, which determined the competitiveness of individual firms and countries. Given that firm restructuring arising from industrial automation may be comparable in magnitude, if not larger, to that of the petroleum refining industry, the focus will now turn to the analysis of some of the key aspects of firm behaviour that have been affected by the new technologies. Because the impact of industrial automation may vary significantly between industries, in process industries the main effect of new technologies is on process control while in batch industry it is over the production process itself, and since most of the relevant research has been industry specific, the section will concentrate on the mechanical engineering industry.

4.1 Production organisation.

It is commonplace in the industrial literature to characterise the mechanical engineering industry as 'mass production'. Definitions of what constitutes 'mass production' vary, but it is generally accepted that it is a form of organisation of production based on the use of single-purpose or dedicated machines by semi- or unskilled workers to produce vast quantitites of standardised goods (Piore and Sabel, 1984). Williams et al (1987) contest this characterisation on grounds that it does not reflect the realities of manufacturing industry, as all production normally takes place under a combination of conditions, including specialised and general purpose machinery, skilled and semi-skilled workers, and varying volumes and varieties of output.

It is beyond the scope of this paper to weigh the strengths and weaknesses of both arguments, except to point out that the empirical evidence suggests that there are other forms of production organisation within mechanical engineering as equally important, if not more, as mass production. We have already mentioned some figures on the share of specialised machinery over total machinery. In addition, studies made in the US and the UK point at production in 'job-shops', i.e. small-batch production with general purpose equipment, accounting for between 50% and 75% of engineering output, and this does not include all general purpose equipment (ECE, 1986).[4] Thus, in examining production organisation, at least both forms of production organisation need to be considered.

There is abundant literature on the impact of 'flexible' automation on 'mass production' in mechanical engineering (Ayres, 1991; ECE, 1986; Edquist and Jacobsson, 1988; Morroni, 1992; Piore and Sabel, 1984). Under this form of production, the main technical and economic problem was that, while transfer machines and moving machining lines had very high output rates, they were rather inflexible and required substantial investment to be modified for cutting a new product. Sometimes they had to be scrapped altogether. If demand is stable and predictable this does not constitute a problem, but if this is not the case, then investing in inflexible equipment was very risky and there were significant trade-offs between specialising and using general purpose equipment. With CNC machine tools or FMS the extent of the trade-off is considerably reduced because the new equipment is nearly as productive as the previous one but is also relatively convertible. Hence, in mass production, industrial automation has led to production flexibility with little cost in efficiency.

In medium and small batch production the technical and economic problem was different (Alcorta, 1995). Before the new technologies were introduced, manufacturing of any product involved selecting the individual machines, deciding the order in which machines were going to be used, and routing the parts through the machines. With a single part this task seems relatively easy, as parts may follow an orderly sequence from one machine to another. But if one considers that the number of machining operations could typically reach 15 or 20 and that they were slow, that not only one part was being machined but up to several hundreds or thousands, that these types of firms typically produce a much wider variety of goods than, for instance, autocomponent firms, that some machines faced higher demand than others, that machines broke down, that machining of individual workpieces had to be coordinated with others that were later joined together in assembly, that some operations required skills that only some operators had, that raw material delivery was not always on schedule, and that some customers had priority over others, it is clear that producing was extremely complex and considerable time lost, a 'nightmare'. In practice, with conventional technologies, medium and small batch producers were very disorganised and inefficient. Studies show that, under these conditions, capital utilisation ratios were very

[4] The share of general multipurpose equipment in use in developing countries may be even higher because of their limited domestic markets.

low. For instance, the time workpieces were actually being cut in a typical job shop was around 4% of the total shift (ECE, 1986).

With the new technologies production management and engineering have eased significantly. There are far less machines to worry about and, in some firms, computers and production management software allow a better coordination of the process. There is still the need to solve the old problems of scheduling, routing and machine use, and new ones like tool management, as the new, more sophisticated tools are becoming a significant part of costs, but the complexity of this task has been reduced. Improvements are visually shown in the shop floor today as it is a much more orderly and cleaner process, with less work in progress and final products inventories, and machines being used for much longer periods. Hence, for medium and small batch producers, the main impact of industrial automation has been efficiency, although at the price of some loss of flexibility, as no machine so far invented has the flexibility of a human being.

Six major results have arisen out of the diffusion of industrial automation in the mechanical engineering industry. First, production processes are becoming more homogeneous accross the industry. Unlike before, when there was much more diversity in the technologies in use between large and small batch producers, today both are acquiring the same 'core' technologies: CNC lathes and machining centres. Larger producers may increase the degree of integration between the equipment and move into FMS in order to have higher production rates or operate unmanned for several hours, but the basic equipment will remain the same. Because of the costs of switching and the uncertainty attached to transfer machines and moving machining lines, even producers of standardised goods are replacing their previous equipment with CNC machine tools and FMS. Second, productivity, particularly among small and medium batch producers, has increased drastically. Productivity increases of 50%-100% were found when moving from conventional machines to CNC machine tools and of 250%-650% when moving from conventional machines to FMS (UNIDO, 1993). Third, capacity utilisation also increases significantly. According to Ayres (1991) increases in capacity utilisation of up to 80% were obtained by firms that had adopted FMS. Other research shows increases in machine efficiency, i.e. hours that machine is actually operating, of over 40% (Alcorta, 1993). Fourth, unit costs fall. Reductions arise from lower labour costs, although there are increases in the spending in training because of the higher skill requirement, savings in the use of raw materials, due to more precise cutting and less waste, and lower energy consumption. Ayres (1991) reports unit costs savings of 41% on average by firms that had introduced FMS. Fifth, product quality improves. Both, product reliability, as measured by the defect rate, and product performance, as measured by the technical features, precision and durability of products, is significantly enhanced (Ayres, 1991; Alcorta, 1995). Sixth, lead times, i.e. the time between getting an order and being ready to deliver it, has also fallen. Unrelated research by Ayres (1991) and Alcorta (1995) found very similar reductions in lead times from 90 days to 2-3 days. Apart from increasing customer satisfaction, reductions of lead times may imply lower financial costs, as it may not be necessary to obtain working capital to finance lengthy production processes.

4.2 Scale and scope.

There was great expectation in the 1980s that new industrial automation would reduce optimal scale while increasing economies of scope. Minimum batch sizes, i.e. quantities of the same product treated in a certain process or sequence of operations, were to be reduced as a result of lower setting-up times and related fixed costs (Hoffman, 1989; Kaplinsky, 1984, 1990). Lower setting-up costs would also make it economically feasible to produce diverse goods, leading to economies of scope (Bailey and Friedlaender, 1982; Baumol et al, 1988). Optimal plant scales would also fall, because of the availability of machinery in smaller capacities and prices (Acs et al, 1990; Acs and Audretsch, 1990a; Carlsson, 1989b; Gilder, 1988; Jaikumar, 1986; Kaplinsky, 1990; Rosenberg, 1988; Piore and Sabel, 1984; Talaysum et al, 1987).

The reality seems to have been very different. While all the research shows that there have been significant reductions in setting-up times and costs, not all of it shows that firms are necessarily reducing batch sizes and increasing product variety (for evidence on falling setting-up times see Alcorta, 1995; Ayres, 1991; Hoffman, 1989; Kaplinsky, 1990, 1991, 1994). As far as batch sizes and product scope are concerned, the more recent evidence suggests that what firms are doing is not so much reducing batch sizes and increasing product variety, but balancing them to the new conditions of production and demand. To explain, let's distinguish again between large and small batch production. Take the case of a large batch producer who has adopted new 'flexible' automation first. Should it face no change or an increase in demand for a single product, then there is no reason why it should produce in smaller batches or more variety. Recall that many 'standardised' goods producers are acquiring 'flexible' automation in the eventuality that demand changes and not because they want to be flexible on a day to day basis. And there are still plenty of 'standardised' products around. If the same producer was manufacturing two products in the same overall volume and the frequency of demand for both products changes over any unit of time, then it can easily adjust and reduce its batch size. This seems to be happening among car component manufacturers, as assemblers increasingly adopt just-in-time techniques, and in these cases batch sizes seem to be falling. However, because there are still some changeover costs, though significantly lower, and since product technology may differ and require new knowledge, process modifications beyond programming, or even very specialised software, the same producer may still find it economically unfeasible to introduce a new product. Take now the case of a small job shop that produced on order and recall that the 'nightmarish' conditions of production were to a very large extent the result of too many products or components moving down the factory. Recall further that problems of production management, scheduling and planning still remain after the adoption of the new technologies. Thus, the degree of product differentiation or the 'average' batch size may continue to be unmanageable and require change.

All these possibilities were found in a recent research summarised by Alcorta (1995). The study was conducted in over 60 developing countries firms from six countries, operating in the car components, capital equipment and customised products industries and which had adopted CNC machine tools. Some 43% of firms had reduced their batch size, 41% recorded no change and 16% had increased it. Product variety had changed in several cases but, more often than not, it was a variation in dimensions or features of previous products. Firms stated that, since industrial automation, batch sizes and product variety had become variables, which had to be closely monitored and assessed. There were increasingly less fixed rules about them.

Turning to optimal plant scale, there is now ample evidence that industrial automation leads towards increasing optimal scale in mechanical engineering (Alcorta, 1995; Altshuler et al, 1984; Bureau of Industry Economics, 1988; Edquist and Jacobsson, 1988; Mody et al. 1991b; Pratten, 1988). The technical reasons for increasing optimal plant scales are much lower setting up time which means that CNC machine tools can spend more of their time actually cutting metal, increase in machining speeds and efficiency, and reduction in number of machines and use of computers and production management software which allows better production organisation and management. The main economic reason is increases in fixed capital costs outweighing reductions in other costs and requiring high machine utilisation rates. Indeed, Ayres (1991) shows that the cost of CNC machining centres, although falling, still remains ten times more expensive than equivalent conventional machine tools, while the cost of CNC lathes is four times conventional lathes.

One possible important effect of higher optimal scales, and thus of industrial automation, is an increase in industrial concentration. For a given market, or in slow growing markets like mechanical engineering, higher optimal scales imply that firms producing at suboptimal levels, and therefore with higher unit costs, will find it increasingly difficult to survive. Lower optimal scale firms will have to make an effort to engage in industrial automation and grow or go out of business because of their uncompetitive costs. Obviously, this can be offset with imaginative marketing strategies, product differentiation or innovative behaviour, as many firms usually do by providing additional services (Pratten, 1991), but the fact remains that firms that are not automated and operate at sub-optimal levels start with a cost disadvantage. And, because the flexibility of new technologies is also available to large producers, these may also be able to compete on differentiated markets. Indeed, in a recent review of this issue Harrison (1994) referring to US based research, pointed out that large metalworking plants were as likely to produce a range of customised products, as were small and medium firms.

The previous point raises the closely related issue of whether new technologies create opportunities for entry by smaller enterprises. During the eighties a considerable literature emerged pointing out at the entry potential created for small firms by industrial automation (Acs et al, 1990; Acs and Audretsch, 1990a; Carlsson, 1989b; Gilder, 1988; Piore and Sabel, 1984). The argument is essentially that, as real incomes and standards of living rise, demand for mass produced goods falls and consumers seek customised and fashionable goods and services. There is a proliferation of 'niche' markets. Because of technological and organisational inflexibilities, large firms are not capable of exploiting the new markets, thus opening opportunities for smaller firms. Industrial automation provides capital goods at prices and sizes that are accessible to small firms. Carlsson (1989b) and Acs and Audretsch (1990a) produce some statistical evidence to support this claim. Using employment-based indicators of size, they show that in metalworking industries in countries such as the US, UK, West Germany, Italy and Japan, the proportion of small firms in the total has increased while, at the same time, the average size of firms in these industries has decreased. As these industries have increasingly used CNC machine tools and robotics, they conclude that automation allows more entry by small firms.

A few points in this connection. First, there is an implicit view in the literature that most consumers in developed countries are of the 'high-income' type, i.e. they only demand better quality, differentiated, and luxurious products as opposed to standardised and cheap goods, demanded by low-income groups. This seems highly counterintuitive, as one would expect to find even in the wealthiest country, a combination of high, medium and low income groups, with the latter two groups stilldemanding standardised goods. Moreover, Sayer (1988) adds that there is no reason to believe that high-income consumers will only demand new and different products. They may sometimes prefer low price or cheap replaceable goods. Besides, the potential demand for cheaper standardised products existing in developing countries is assumed away. Second, the question of cheap and divisible capital goods comes once and again. Two comments in this regard. On the one hand, the confusion would seem to arise because most of the literature compares the price of today's 'cheap' industrial automation with the price of 'expensive' transfer machines. It has already been pointed out that transfer machine was not the dominant technology in metal cutting. The relevant comparison is, therefore, with conventional technology. But even if one compares with transfer machines, there is not much difference between costs and latest automation may be even more expensive if a sophisticated FMS with many CNC machine tools is required[5]. On the other hand, equipment is divisible only if compared with a transfer machine in the sense that one does not have to purchase a whole FMS but can build it through time. But it also means that one may not be able to produce equivalent products. Both situations are not strictly comparable. Of course one could think of a number of small firms buying each one a CNC machine tool and machining parts of the product independently. But this would imply that the production and technical complementarities of the new technologies (Milgrom and Roberts, 1990; Morroni, 1994) are not achieved and it may prove far more 'expensive' to ship a bulky piece around for machining than to machine it under the same roof. No volume car producer or aircraft manufacturer would ship around an engine block for machining. Third, the level of aggregation of the data, two-digit industry, which the evidence is based on, implies a wide variety of establishments which may have little in common with each other and does not help to discern which type of firms are adopting what (Harrison, 1994). Indeed, where appropriate surveys have been used in the US, UK, Germany and Italy, the results show a strong correlation between plant size and use of automation (Harrison, 1994). Fourth, according to Harrison (1984) the trend towards a larger share of employment in small firms should have happen anyway for no other reason than the movement from industrial and metalworking sectors with large numbers of employees such as steel, automobiles and aircraft to the services sector which typically has smaller units of production. But that

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[5]Information provided by a Spanish supplier of transfer machines. The supplier also pointed out that for machining engine blocks it was still cost effective to do so with transfer machines and that they were supplying major Japanese car producers.

despite this factor, if inspected carefully the data for Japan and Germany over the last twenty five years actually shows no upward trend in the share of employment in metalworking small firms and a moderate growth at plant level but not at firm level in the US. Only in the UK has there been an increase in the share of employment by small firms but this has been the result of recession and deindustrialisation more than anything else. In conclusion, there does not seem to be any a-priori reason nor evidence supporting claims that new technologies favour smaller producers; if anything, they seem to be favouring larger ones[6].

4.3 Vertical integration and inter-firm relationship.

Another popular view during the eighties, which also contributed to the view of an increasing role for small firms, was that industrial automation would lead to vertical disintegration. According to Harrison (1994) this view was based on the observation in the early seventies of large corporations hiving-off activities that formerly had been performed within the firm. For years firms had overstretched themselves and under pressure to recover profitability were forced to concentrate on core competences and exit activities were there were low or no complementarities. Many of these activities were hived-off to former employees of the corporations which started their own smallbusiness and then developed close cooperative relations with their previous former employers. The increasing 'divisibility' of new technologies made it all possible because it allowed workers either to buy their machines off from their former employees or to purchase their own production equipment, thus costing little in terms of production and productivity to the corporations.

To examine this claim it is necessary first to distiguish between final assembly of, for instance, automobiles, and machining of components. In the case of assembly the claim seems to be on firmer ground as there is considerable evidence arising particularly from the car industry that
under pressure to reduce costs final assemblers are requesting certain component manufacturers to undertake the production of a range of parts, sections or systems of a vehicle rather than having to put them together themselves. The idea is to have the component manufacturers delivering just-in-time whole sections or systems of the vehicle, reducing the number of final assembly steps and, as a result, easing

[6] This may not be the case in all industries. In new or high tech industries like electronics or software the possibilities for entry and innovation by smaller firms are much larger than in established low to medium tech industries.

significantly the assembly process. It is true that to achieve this it is necessary to coordinate closely product development between final assemblers and component manufacturers, which is leading to new patterns of cooperation characterised by intense interaction but, what is less clear, is whether this kind cooperation involves a two-way relationship or mere imposition of final assemblers' wishes over component producers. It is also not very clear, whether the main beneficiaries of this 'hiving-off'are going to be small producers or the large component producers as producing and delivering sections or systems for vehicles requires considerable engineering capabilities.

For component manufacturers the situation seems to be different as industrial automation would seem to be leading not so much to disintegration but, on the contrary, to vertical integration. Alcorta (1993, 1995), on the basis of the developing countries firms mentioned earlier and interviews among European firms found that one key effects of industrial automation had been increasing internal production of components that were previously farmed out. This was found to be the case for car component, capital goods and customised products manufacturers. One British manufacturer of book-binding equipment stated that before they acquired their FMS their suppliers employed around 30 staff. All those jobs have now gone because they are producing in-house all components except for very basic ones like screws, nuts and bolts, which were being outsourced before anyway. The reasons for such change were that the new equipment had such a production capacity and relatively low setting up times that the only way to keep it fully utilised was by producing components internally. Some firms in developing countries declared that the new equipment allowed for machining complex components which previously had to be imported. It was far easier to learn product and process component technology than new product technology because firms were already familiar with the components. Thus, component producers were simultaneously under pressure from final assemblers to diversify and from the new technologies to integrate vertically.

4.4 Research and development (R&D).

In the early discussion on the impact of industrial automation on the mechanical engineering industry much was said about the increasing R&D requirements of the new technologies. As far as product technology is concerned the new technologies require significant efforts in product design including the development of 'design for assembly' and 'design for producibility' techniques. These techniques consist not only of designing a number of standard and interchangeable parts, but completely redesigning all parts and products and most of the productive process with the help of computers capable of modeling physical processes. In this way, the number of components can be reduced and products can be easily manufactured with as few jigs and fixtures as possible. Design for assembly and producibility techniques require detailed written knowledge of product and production process and the capacity to write complex programs which, in many cases, are factory specific, and require an in-house software writing capability (Bolwijn et al, 1986). As far as process technology is concerned research effort is needed prior to installation if serious operating mistakes are to be avoided. Early estimates were that preinstallation studies of a sophisticated FMS could take up to two years (UNIDO, 1991b). Getting an FMS to operate correctly requires solving complex integration and communication problems and prior experience in handling high-tech equipment. Problems get compounded if the new technologies are linked to accounting or management systems. Because some FMS installations are specific combinations of technology, involving different elements for different firms, writing the software for linking elements into a network so that pieces of equipment can 'talk intelligibly' to each other is particularly difficult.

The experience with the impact of industrial automation on the research and development effort has been much more mixed than what the early literature anticipated. To begin with, imitation or minor product modification and adaptation has been considerably eased with the use of CAD. Edquist and Jacobsson (1988) point out that CAD software embody enough accumulated design and draughting knowledge as to adapt product design to local market conditions, match raw material and component availability and 'read' specifications from users which are also written in 'CAD terms'. CAD has also increased the productivity of design engineers meaning that fewer engineers are required to finish a given design. Many developed and developing country firms studied in Alcorta (1993, 1995) were using CAD, had not modified their product technology significantly and were not spending significantly more on research and development.

New product research and development is a different matter altogether. Take the case of machine tool production according to the account of Jacobsson (1985, 1989). In the early 1970s the production of conventional machine tools was based on metallurgy and mechanics and product technology was well established. Developing a new machine tool today requires a substantial 'mass of skills' and a much larger number of design engineers. It involves a considerable backlog of knowledge in, and the integration of, old disciplines such as physics, chemistry, mathematics, electrical and mechanical engineering, together with new ones, such as computer science and electronics. Machine tools today have a large share of electrical and electronic components accounting for around 30% of manufacturing costs. New machine tool development also involves experimentation by developers in their own production process as well as considerable adaptation, modification and further refinement, and therefore learning. The development of new products and key components for items such as home electrical appliances, transport equipment of all kinds, all type of machinery, power equipment and most electrical equipment generally require today of a similar research and development effort as the one described for machine tools.

Turning to the research and development effort required for process development there have also been some advances since the first CNC machine tools and FMS were made available. One first advance is that many suppliers have been able to develop configurations of equipment that, can with little modifications, adapt to varying circumstances. The more complex processes, however, still require an in-house capability for process development or the support of outside specialised consultants. There has also been a trend towards the standardisation of CNC machine tools. Another advance that is reducing the difficulty of software writing is the application of modular techniques to software development. It is no longer necessary to start from scratch whenever a new programme has to be written but one can build on what others have done on the basis of only adding or removing parts or 'modules' of programmes. This task is eased even further by new software and computers specifically aimed at the development of software.

4.5 By way of summary.

The underlying expectation in the early literature on industrial automation was that it would radically impact mechanical engineering but that the impact in terms of industrial organisation would be, by and large, benign. This meant that the rigidity attached to old technologies and forms of organisation would be superceded by more flexible ones, large optimal scale would fall significantly, variety would increase, entry by small firms would increase considerably, vertical disintegration would ensue and innovation would be at the order of the day. What we have been trying to point out here is that the impact of automation on the mechanical engineering has certainly been radical, but not of the kind described by the literature. Production in mechanical engineering would only be more flexible if mass production was the been dominant form of production organisation but this has not been established, in fact, the balance of evidence goes in the opposite direction. Optimal scale has not fallen but increased which will most likely result in higher industrial concentration. Vertical integration has not reduced but increased as far as middle range component manufacturers are concerned. Today we have slightly less vertically integrated but powerful and very large final assemblers which call the tune for the whole industry, highly integrated and large second-tier component manufacturers and, a smaller number of third-tier component producers because the machining capacity concentrated in second-tier firms has increased drastically. Production innovation has not eased but become more difficult as more and more of the value added of the industry begins to be accounted for by the electronics industry. Fortunately imitating, adapting and copying has not become more difficult but this will also depend on the stringency on the new rules for appropriability of innovation. On the whole, the overall trend in the industry is not towards small firm dominance but towards oligopolisation and severe cost-cutting and price competition very much in the way the petroleum refining industry was transformed following the innovations which began in the 1920s.

Before moving on to the next section a couple of points regarding the impact of industrial automation on industrial organisation in other industries. First, batch industries are likely to be affected more than continuous process industries. Because of the significant rise in the capacity to process information since microelectronics it is increasingly possible to account for the frequent and sizable variations from steady state situations and develop models which can reproduce complex production processes accurately. In addition sensor technology is also developing rapidly permitting accurate and 'real time' measurement and action under varying circumstances. This suggests that industrial automation will diffuse also to other activities within mechanical engineering as well as to other industries. Within mechanical engineering, automation of metal forming had proved difficult because of the large sizes of the workpieces. This has started to change with the recent development of CNC cutters and benders which are capable of 'looking' into very large areas. In painting, welding and assembly advances in robotics are being boosted by vision recognition and artificial intelligence permitting the development of even more sophisticated robots. Beyond mechanical engineering microlectronics is leading to advances in automation in all industries. In printing, for instance, presses now are capable of printing in four colours without having to be reset following the development of a computer-controlled four-body integrated press. In textiles and clothing and leather and leather products automatic sewing machines and laser cutters are already available. Although the progress of industrial automation within and between batch industries, and from production processes into other activities of the firm such as accounting or management, seems to be steady it is unlikely that in the forseable future we will see completely unmanned factories as the technology to do so does not seem available yet or is totally uneconomical.

Second, as far as continuous process industries is concerned, because industrial automation does not change the production process but the control of the process it is likely to have less impact than in batch industries. In continuous process industries the major impact will be on the conditions of operation resulting in some additional flexibility in product formulation, savings in energy and use of raw materials and improvements in the safety and environment record of plants but no major upset in industrial organisation should be expected.

V. IMPLICATIONS FOR DEVELOPING COUNTRIES' INTERNATIONAL COMPETITIVENESS.

Thus far the paper has argued that the development of industrial automation has been an historical process that involves the use of machines with feedback controls. That the diffusion of industrial automation has concentrated in developed countries while developing countries, with the exception of South Korea, Taiwan, China, and to some extent Brazil, either produce or use very little industrial automation equipment. And, that the diffusion of industrial automation is resulting in deep transformations particularly in batch industries, and within them in mechanical engineering. These transformations include making the production process more homogeneous across the industry, increasing oligopolisation of the industry and intense price and cost-cutting competition.

What prospects then for the development of an internationally competitive export oriented industry by developing countries? What prospects for the mechanical engineering industry? The questions seems to be even more pressing if one considers first, that the products that are being affected by industrial automation in the mechanical engineering industry such as as home electrical appliances, transport equipment of all kinds, all type of machinery, power equipment and most electrical equipment constitues a very large share of total manufacturing output in many developing countries (Edquist and Jacobsson, 1988). Secondly, the world economy is becoming more open to international trade and there is increasingly less room for protection and non-tariff barriers to international trade (Cooper, 1995). This second point is particularly important as most of the above mentioned products were heavily protected in developing countries.

Within a simple choice of technique framework developing countries should be doing very little, if anything. Labour is relatively cheap in these countries so they should specialise in labour intensive goods. Because conventional technology is much more labour intensive that automated equipment, developing countries should concentrate on the use of the former technology. If developing countries had promoted through protection or other interventionist policies the development of a mechanical engineering industry and the diffusion of some industrial automation, they have done so wrongfully and would only do them good to reverse this decision.

There may be some truth in this view in the sense that developing countries may have promoted the diffusion of any type of industrial automation without due care of the relative price issue. The use of advance FMS or robotics can hardly be justified in most developing countries. Relative price considerations are relevant in these specific circumstances but do not seem to be relevant regarding industrial automation at large. For one part, it fails to see the deep transformation it creates in terms of cost structures and industrial organisation which in a not too long temporal horizon, can significantly change the previous static comparative advantage of any developing country. For the other, it fails to see the dynamic impact of the more advance technologies in the learning processes of industries and the positive externalities that the diffusion of advance technologies may have on industrial development of any developing country. It condems developing country firms to no role in an increasingly internationalised and oligopolised industry because industrial automation will be the dominant technology in the mechanical engineering industry in the near future. Thus, not promoting the diffusion of certain kinds of industrial automation would seem to be as mistaken as unrestricted promotion based on no consideration of relative prices.

If some kind of industrial automation needs to be promoted in developing countries the first issue that arises is which kind of industrial automation? Alcorta (1994), Edquist and Jacobsson (1988) and Watanabe (1992) argue that the industrial automation technologies that should be emphasised most are CNC machine tools and CAD. The main reasons for choosing these technologies are first, they provide an 'entry point' to industrial automation without the significant capital investment of the most advanced robots or FMS. Furthermore, it is in the integration of different CNC machine tools into an FMS were largest savings in labour are achieved, so by adopting solely CNC machine tools loses in the relative abundant factor are minimised. Secondly, both CAD and CNC machine tools have significant engineering and operating skill saving features. To the extent that engineering and operating skills are in relative short supply in developing countries promoting the diffusion of these technologies seems highly appropriate.

The second question that needs to be addressed is whether the new technologies should be developed locally or imported. The trade-offs between the make and buy decision are quite apparent. On the one hand, successfully producing CNC machine tools locally has a number of advantages. First, as was pointed out before, the manufacture of CNC machine tools provides a combination of breath and depth of knowledge and disciplines and research and development intensity that is difficult to achieve in any other industry. Second, since the development of a machine tool industry requires close interaction with the users, the learning potential is not only high but is also widely diffused through industry, thus helping to build not only sectoral specific technological capabilities but also national capabilities. Put it in a slightly different way, positive externalities are exceedingly high in CNC machine tool manufacturing. Furthermore, the evidence shows that a local industry is normally more inclined than a foreign one to provide a good repair and maintenance service (Edquist and Jacobsson, 1988). Third, the development of a competitive domestic capital goods industry can be an accelerating factor in the narrowing of the technological gap between developed and developing countries. On the other hand, because the pace of technological change in the international machine tool and process control industries is very rapid, the prompt local diffusion of foreign industrial automation becomes crucial in order to avoid losing international competitiveness in user industries.

Apart from South Korea and Taiwan at the moment only a Brazil, India, Singapore and possibly China are producing CNC machine tools and process control technology in any significant amount. All other developing countries do not have the level of demand and the skills to sustain the development of a local CNC machine tools and process control industry. Even in Brazil an India there are doubts about the economic feasibility of domestic production and local CNC machine tools producers have lost considerable market share following the opening towards foreign competition. Thus, in this context it would seem inadvisable, in the foreseable future, for most of the other developing countries to embark in the development of local production of industrial automation but rather to focus on the promotion of the diffusion of foreign technology to ensure the competitiveness of user industries.

The third issue that arises in this context refers to whether there are any obstacles to the diffusion of industrial automation in developing countries. Indeed there seem to be several main obstacles and barriers to the diffusion of new technologies (Alcorta, 1995; Edquist and Jacobsson, 1988; Vuorinen, 1992; Watanabe, 1992). First, macroeconomic limitations. It is frequently pointed out that high inflation rates or exchange rate volatility, foreign trade restrictions and lack of demand for local engineering goods constitute a major limitation to the diffusion of industrial automation. High inflation rates or exchange rate volatility affect the diffusion of industrial automation by creating an environment that is risky and uncertain and, as a result, not conducive towards investment, particularly if the investment is large and the recovery period long. Foreign trade restrictions limit diffusion by making available to local users only a narrow range of equipment, which is normally not of the quality and price required by most local users. Second, lack of information about the new technologies. It is often the case that developing country firms, particularly local medium and small firms, are not fully aware of the availability and features of new technologies nor have had any experience with them. Third, lack of availability of skills. In many developing countries there are acute shortages of engineering, operating and repair and maintence skills which are an absolute prerrequisite to the diffusion of industrial automation. Fourth, the absence of local representative of foreign suppliers. Absence of locally based representative of foreign suppliers normally implies that no one can provide the maintenance and services required for the normal functioning of foreign technology. Having to get a foreign technician every time a CNC machine tool breaks down or requires maintenance may take a long time and prove very costly in financial and lost production terms. Foreign representatives also ncessary for training local personnel. However, it is important to be aware that foreign representatives of suppliers are not always as willing to provide information as they could be. Fifth, lack of institutional and infrastructure support. The effective use of industrial automation normally requires the support of a variety of institutions including metrology institutes and industrial extension and training centres which are very useful in firms' learning processes. These institutions are not always available in the number and quality necessary to promote the diffusion of new technologies.

Obstacles to the diffusion of new technologies need to be removed through the action of public policy. There are at several ways in which the state can act in the promotion of the diffusion of new technologies. The first one is providing a stable macroeconomic environment. Particularly Latin American and African countries have faced during the 1980s persistent macroeconomic and balance of payments disequilibria that have seriously impaired their capacity to adopt new technologies. A sound monetary fiscal and monetary policy are therefore key aspects of public policy to ensure successful diffusion. The second area is the institutional and information support system. Policy should promote the establishment of public and private institutions concerned with the dissemination of information and the provision of industrial extension services such as standards and measurement offices and specialised research institutes. The third area is the development of an educational and training sector that provides the necessary skills in the number and quality required. The educational sector should be capable of providing as many levels of skills as could be required but ensuring that there is little social distinction between the different levels of skills. Finally, public policy should provide direct support selectively in the form of financial assistance, tax concessions or subsidy to private and public initiatives that may promote the diffusion of a specified range new technologies.

VI. CONCLUDING REMARKS.

Ever since the industrial revolution began a systematic and sustained endeavour to substitute machines for human effort. Mechanisation or machinofacture, the first phase in this endeavour was achieved through the development of machines which replaced human or animal power with mechanical power. The second major phase in this endeavour, industrial automation, which builds on mechanisation but is distinctly different because of the use of feedback control, is a twentieth century phenomenon and began around the 1920s in continuous process industries, spreading into batch industries around the 1950s. Yet, industrial automation only matured with the emergence of microelectronics which allowed for a radical leap in automatic control.

The diffusion of industrial automation since the advent of microelectronics in the 1970s has proceeded at a very fast rate. In continuous process industries more powerful and sophisticated process control units and sensors were developed while in batch industries, particularly in mechanicalengineering, new process equipment such as numerically and computer controlled machine tools, computer-aided-design and flexible manufacturing systems emerged. Use of these technologies is asymmetrical with developed countries accounting for the largest share of industrial automation while developing countries accounting only for a minor share of the total, and this is concentrated in three or four countries, South Korea, Taiwan, China and to some extent Brazil. Other developing countries are being excluded from the benefits of technical change.

Industrial automation is resulting in major restructuring of manufacturing industry in general and mechanical engineering in particular. Unlike the early expectations of the literature, the production process is becoming more homogeneous and efficient, significant increases in productivity and reductions in unit costs are taking place, optimal scales of output and vertical integration are increasing and product innovation getting much more demanding, leading to growing industry concentration. Large internationalised oligopolies, with few exceptions based in developed countries,are taking a pivotal role in industry's fate either by increasing their market share or indirectly throughtheir control of key steps in the productive chain. Meanwhile, developing country firms are increasingly being relegated to minor partners in a new 'international division of labour'.

Developing countries firms thus face the choice of accepting this position or competing head on with their most advanced counterparts. Doing so, however, involves reaching and surpassing the productivity, unit cost and quality levels of their more advanced counterparts. While there is some room for consideration of relative prices issues, by and large, competition will involve using some of the most up-to-date production technologies. Developing countries will, therefore, have to increase their local absortive capacity to use advanced technologies. This will require sustained public and private efforts to achieve macroeconomic stability, disseminate information on the availability anddevelopments in industrial automation and, promote the creation of the necessary skills and institutional and infrastructure support. Failing to do so would probably mean that developing countries will also be left out from this second major phase in human development.

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APPENDIX 1: APPARENT CONSUMPTION OF INDUSTRIAL ELECTRONIC CONTROL EQUIPMENT IN 1993 (US$ MILLION)

	TOTAL ELECTRONIC EQUIPMENT[1]	Industrial Control Electronic Equipment								
		Control and Instrumentation				Medical and Industrial		Components		
		Total	Of Which			Total	Of Which	Total	Of Which	
			Industrial and Process Control	Instruments	Accessories and Parts		Industrial		Active	Passive
TOTAL	738098	64869				27768	8729	198498	108346	55368
1. Developed Countries	607527	53381	19747	27266	3908	23254	7821	153543	84730	41820
a. Western Europe	196857	21716	8781	10016	2917	7210	3514	40454	17169	13577
Germany	49130	6379	3961	1988	430	1962	1316	10582	4066	3969
Italy	22881	2839	1380	1290	168	736	188	4378	2348	1180
Switzerland	6751	1056	436	428	192	300	97	1010	369	[illegible]
United Kingdom	32094	3240	1463	1284	494	1112	696	7042	3155	2260
France	31697	2904	958	1448	498	988	346	6127	2801	1816
Netherlands	12602	1534	188	880	466	626	136	1942	546	812
Other[2]	41702	3764	395	2698[6]	669	1486	735	9373	3884	3178
b. North America	266400	24994				10998	3339	63856	38788	15249
United States	250360	23243	8633	14610	[7]	10335	3144	61038	37203	14656
Canada	16040	1751	na	na	na	663	195	2818	1585	593
c. Far East	144270	6671				5046	968	49233	28773	12994
Japan	137018	5964	2333	2640	991	4829	919	48297	28378	12721
Australia	7252	707	na	na	na	217	59	936	395	273
2. Eastern Europe[3]	15321	2593				868		2693		
CIS	9572	1830	na	na	na	545	na	1785	na	na
Other	5749	763	na	na	na	323	na	908	na	na
3. Developing Countries	115250	8895				3646	1326	42262	23616	13548
a. Asia	82563	6194				2120	908	35204	20020	11335
China	18903	1530	na	na	na	637	260	5983	2850	1498
India	4119	313	na	na	na	125	35	936	464	1065
South Korea	17898	1708	377	1124	207	443	187	8321	5158	1803
Taiwan	10886	705	na	na	na	228	87	6458	3935	1815
Singapore	12154	732	na	na	na	127	66	5845	2157	1756
Malaysia	7337	544	na	na	na	135	77	4207	1685	1412
Others	11266	662	na	na	na	425	196	9434	3771	1986
b. Latin America	23843	1850				787	217	5556	2531	1513
Brazil	14511	1000	na	na	na	358	123	3179	1403	903
Others[4]	9332	850	na	na	na	429	94	2377	1128	610
c. Africa & Middle East[5]	8844	851	na	na	na	739	201	1502	1065	700

[1] Includes electronic data processing, office equipment, control and instrumentation, medical and industrial, communication and radar, telecommunications, consumer and components.
[2] Includes estimates for Greece and Portugal.
[3] Estimated.
[4] Includes estimates for Mexico and Venezuela.
[5] Includes estimates for Egypt, and Saudi Arabia.
[6] Includes process control for Belgium, Finland, Ireland, Norway, Spain, and process control and accessories for Portugal.
[7] Included in process control and instrumentation.

Source: Elsevier's Yearbook of World Electronics Data 1993, 1994, and 1995

APPENDIX 2: WORLD MACHINE TOOL PRODUCTION, 1977-93
(millions of US$)

	Machine Tool Production (US $ mn)					Structure of Production by Country (%)					Growth Rate of Machine Tool Production (%)					
	1977	1981	1986	1990	1993	1977	1981	1986	1990	1993	77-81	82-86	87-90	91-93	77-90	77-93
World	15110	26353	28775	46588	28249	100	100	100	100	100	12.3	1.1	8.0	-12.0	7.0	6.2
Developed Countries	10065	19154	20791	35513	22433	66.6	72.7	72.3	76.2	79.4	14.3	1.3	9.7	-11.3	7.7	7.1
Western Europe	5933	8907	10922	21156	11647	39.3	33.8	38.0	45.4	41.2	11.2	1.6	8.8	-11.9	6.8	6.4
Western Germany	2635	3953	5185	8827	5145	17.4	15.0	18.0	18.9	18.2	11.1	1.3	5.1	-13.3	6.7	6.5
Italy	8781	1513	1623	3966	2366	5.8	5.7	5.6	8.5	8.4	12.9	2.0	11.9	-10.0	7.9	7.7
Switzerland	580	846	1424	3184	1354	3.8	3.2	4.9	6.8	4.8	11.0	5.6	10.4	-10.9	8.8	7.8
United Kingdom	588	933	916	1720	953	3.9	3.5	3.2	3.7	3.4	14.6	-0.5	12.9	-9.6	6.2	5.2
France	591	809	657	1365	618	3.9	3.1	2.3	2.9	2.2	9.2	-3.0	12.0	-12.2	2.9	2.6
Other	661	853	1117	2094	1211	4.4	3.2	3.9	4.5	4.3	7.7	2.3	11.0	-12.1	6.3	5.9
North America	2512	5380	2957	3509	3615	16.6	20.4	10.3	7.5	12.8	15.5	-9.3	5.5	-0.3	2.6	2.4
United States	2441	5111	2748	3140	3275	16.2	19.4	9.5	6.7	11.6	15.2	-9.6	4.8	-0.3	2.0	1.9
Canada	71	269	209	369	340	0.5	1.0	0.7	0.8	1.2	24.5	-5.4	12.3	-0.3	13.5	11.7
Far East	1623	4867	6912	10848	7171	10.7	18.5	24.0	23.3	25.4	21.0	8.4	13.1	-14.6	13.9	12.5
Japan	1602	4798	6872	10832	7154	10.6	18.2	23.9	23.3	25.3	21.1	8.5	13.3	-14.6	14.0	12.6
Australia	18	69	40	16	17	0.1	0.3	0.1	0.0	0.1	12.4	1.4	-32.9	-6.9	4.7	2.4

Eastern Europe	4131	5659	6228	7475	1680	27.3	21.5	21.6	16.0	5.9	7.2	0.0	2.0	-36.1	4.7	1.4
Former USSR	2202	2932	3672	4580	1133	14.6	11.1	12.8	9.8	4.0	7.2	2.0	4.6	-42.6	5.2	2.8
Eastern Germany	641	828	1001	1085	0	4.2	3.1	3.5	2.3		6.3	0.8	-0.9		4.9	
Other	1288	1899	1555	1810	547	8.5	7.2	5.4	3.9	1.9	7.7	-4.3	-1.6	-10.5	3.5	-0.5
Developing Countries	914	1540	1756	3600	4136	6.0	5.8	6.1	7.7	14.6	10.7	3.2	7.3	0.8	8.4	8.8
Asia	565	1176	1369	3080	3758	3.7	4.5	4.8	6.6	13.3	14.6	3.1	10.3	1.4	11.2	11.4
China	355	440	364	990	1753	2.3	1.7	1.3	2.1	6.2	4.6	-4.5	9.9	6.8	4.9	6.9
India	89	209	270	244	156	0.6	0.8	0.90	0.5	0.6	15.0	7.7	-2.1	-9.2	10.1	7.8
R. of Korea	57	178	33	733	623	0.4	0.7	1.2	1.6	2.2	23.9	6.0	9.1	-9.4	18.0	16.8
Taiwan	58	294	367	1035	1074	0.4	1.1	1.3	2.2	0.5	34.8	10.9	15.4	1.6	21.0	19.6
Other	6	55	35	78	152	0.0	0.2	0.1	0.2	0.5	43.9	-11.9	18.1	7.4	19.9	19.7
Latin America	349	364	387	510	377	2.3	1.4	1.3	1.1	1.3	2.5	2.6	-5.1	-2.7	0.8	0.7
Brazil	283	305	370	450	362	1.9	1.2	1.3	1.0	1.2	2.8	5.4	-6.0	-3.4	1.3	1.1
Other	66	59	17	60	51	0.4	0.2	0.1	0.1	0.2	0.9	-20.1	2.8	1.2	-3.5	-2.5
Africa				10	1					0.0				-7.1		-13.2
South Africa				10	1					0.0				-7.1		-13.2

Source: American Machinist.

Appendix 3:World Machine Tool Consumption, 1975, 1980, 1985, 1990-3
(millions of US $)

	1975	1980	1985	1990	1991	1992	1993
World	**12196.6**	**24971.1**	**20180.0**	**42421.8**	**39344.0**	**30784.1**	**25651.0**
Developed Countries	**7230.2**	**16111.1**	**12735.9**	**30270.7**	**28535.8**	**22417.9**	**17515.5**
Western Europe	**3837.3**	**7539.0**	**4961.0**	**17025.4**	**15222.7**	**12644.1**	**8129.2**
West Germany	809.0	2545.0	1814.7	5849.5	6046.7	4848.0	2966.1
Italy	653.5	1260.1	638.0	3019.8	2718.1	2313.4	1611.1
Switzerland	220.2	349.3	296.6	1184.9	704.4	573.2	372.4
UK	618.6	1344.6	729.4	1738.9	1364.6	1246.4	1007.6
France	695.4	992.0	589.7	2419.1	1924.5	1666.6	954.0
Other	840.6	1048.0	892.6	2813.2	2464.4	1996.5	1218.0
North America	**2465.9**	**5867.1**	**4285.3**	**5537.4**	**4903.7**	**4302.7**	**5398.1**
United States	2201.7	5325.5	3855.0	4714.4	4340.1	3733.7	4765.0
Canada	264.2	541.6	430.3	823.0	563.6	569.0	633.1
Far East	**927.0**	**2705.0**	**3489.6**	**7707.9**	**8409.4**	**5471.1**	**3988.2**
Japan	824.6	2532.7	3393.3	7617.5	8327.4	5370.1	3887.2
Australia	102.4	172.3	96.3	90.4	82.0	101.0	101.0
Eastern Europe	**3830.6**	**6270.5**	**5464.0**	**7319.6**	**4902.6**	**2275.0**	**1770.7**
Former USSR	2286.6	3751.0	4112.4	5700.0	4220.0	1610.0	1203.6
East Germany	268.8	453.7	157.8	600.0			
Others	1275.2	2065.8	1193.8	1019.6	682.6	665.0	567.1
Developing Countries	**1135.8**	**2589.5**	**1980.1**	**4831.5**	**5905.6**	**6091.2**	**6364.8**
Asia	**508.4**	**1494.8**	**1555.9**	**3904.6**	**4722.3**	**5222.8**	**5736.4**
China	351.0	532.0	555.8	1115.4	1819.8	2325.8	3075.4
India	118.7	216.2	424.1	328.3	311.8	367.5	324.1
Korea		452.8	308.9	1549.3	1643.9	1432.8	1212.9
Taiwan	38.7	191.9	165.0	597.6	646.4	826.9	827.2
Others		101.9	102.1	314.0	300.4	269.8	296.8
Latin America	**525.9**	**864.5**	**343.6**	**795.4**	**728.5**	**810.6**	**582.6**
Brazil	206.0	418.9	152.2	481.5	291.4	203.3	220.5
Others	319.9	445.6	191.4	313.9	437.1	607.3	362.1
Africa	**101.5**	**230.2**	**80.6**	**131.5**	**454.8**	**57.8**	**45.8**
South Africa	101.5	230.2	80.6	131.5	454.8	57.8	45.8

Source: American Machinist, several years