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New Technologies, Scale and Scope, and Location of Production in Developing Countries.

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I. INTRODUCTION

Ever since Adam Smith's famous dictum 'the division of labour is limited by the extent of the market', the issue of scale and economies of scale has figured prominently in the economics discussion. Smith pointed out that larger markets permit greater specialisation of labour and machinery, which leads to significant unit cost reductions. Other factors, such as technological relationships, permitting equipment having greater capacity at a less than proportional increase in investment, and indivisibilities, which make it worthwhile to spread the costs of lumpy equipment, initial product development or setting-up machines over a larger output, have also been considered sources of economies of scale.[1]

Developing countries' industrialisation has always been limited by increasing scales. The small size of their domestic markets has meant that industries could not be established or that, when established, firms would be producing lower volumes and at unit costs far higher than efficient plants. Producing at suboptimal levels, in turn, required high domestic protection, with the attendant effect on social welfare. Changes in consumer preferences, income levels, macroeconomic conditions and/or the degree of foreign competition would lead to unused capacity and, therefore, even higher unit costs and more protection, or to the closure of the facility. Exports could provide a way out to the scale problem, but a minimum of efficiency is often necessary prior to entering foreign markets.

It is claimed that new technologies (NT), particularly microelectronics-based forms of automation and design and associated organisational techniques, are leading to fundamental changes in economies of scale (Acs et al, 1990; Acs and Audretsch, 1990a; Ayres, 1991; Ayres and Miller, 1983; Auty, 1992; Benson, 1989; Benson and Ponton, 1991; Carlsson, 1989b; Gilder, 1988; Hoffman, 1989; Jaikumar, 1986; Kaplinsky, 1984, 1990; Piore and Sabel, 1984; Rosenberg, 1988; Talaysum et al, 1987). It is said that the increasing replacement of mass production, specialised, single-purpose, fixed equipment by computer-controlled flexible automation is resulting in falls of optimal scales of output or 'de-scaling' while, at the same time, raising the flexibility of production units to switch to the manufacture of a wider variety or scope of goods. One important consequence of falling optimal plant and firm scales is that entry by small-scale flexible producers becomes possible (Acs et al, 1990). This 'de-scaling' view is

[1]Bain (1954, 1956) and Sylos-Labini (1962), in turn, brought scale issues into the area of industrial organisation by arguing that scale could emerge as a powerful 'barrier to entry' to potential producers in an industry. Bain maintained that scale becomes a 'barrier to entry' because each industry may have a minimum scale, measured as percentage of industry size, at which firms secure minimum cost operation --i.e. minimum efficient scale (MES). Potential entrants producing at a smaller scale would suffer a cost disadvantage vis-a-vis established producers.

shared by a large proportion of the economics, management and engineering literature that focuses on the impact of recent technical change on scale in manufacturing production.

'De-scaling' could have important consequences for industrialisation and regional progress in developing countries, according to this literature. It may increase the efficiency of small-scale production, and, insofar as scale is a barrier to entry, lead to more entry and competition. It may facilitate the establishment of national industries where it was not feasible due to market size limitations. It may ease the 'infant industry' process by allowing a more widespread impact of the various forms of learning associated with experience and of the 'externalities' resulting from the acquisition and use of new knowledge. It may enhance opportunities for local small manufacturing firms to compete successfully in international markets. And, finally, it could pave the way to new patterns of decentralised industrialisation based on small production units located outside the large urban centres.

The potential impact of 'de-scaling' on developing countries clearly warrants careful examination of the issues involved. Accordingly, the main aim of this paper is to present the results of an international research on whether and to what extent NT have diffused to developing countries, and what their effect has been on product, plant and firm scale and scope. Granting that the overall impact of NT on scale is very difficult to gauge at this stage, as some of the newest technologies have not completely 'diffused' in developing countries, the paper will argue that, although NT have permitted the production of a relatively wider scope of goods, and have the potential to reduce product scale, they have not led to a reduction of plant and firm scales. In fact they have led to 'scaling-up' rather than 'de-scaling' because of the higher efficiency of the new forms of automation and because of high capital and other fixed costs.

The paper will proceed as follows. The next section will present a simple conceptual framework examining the relationship between technical change and costs and how it may lead to 'de-scaling' or 'scaling-up'. The paper will then briefly review the literature on the nature of the technological changes that are affecting the manufacturing industry and the arguments put forward by 'de-scaling' authors and their critics. The third section will examine the process of diffusion of NT in the engineering industry in a selected sample of developing countries. The next section presents our empirical findings on scope and product, plant and firm scale. The paper will end with some comments on the impact of NT on the prospects for industrialisation in developing countries.

II. TECHNICAL CHANGE, COSTS AND OPTIMAL SCALE

The impact of technical change is often discussed in terms of shifts in the production function, but it can also be approached from the cost side. In this case, given a set of factor and/or input prices, technological change may allow the firm to produce a higher level of output at the same cost, or the same level of output at a lower cost.

In multi-product firms technical change may lead to lower costs not only due to savings in producing individual goods but also in producing goods jointly. Baumol et al (1988) and Bailey and Friedlaender (1982) argue that, until refrigeration and fast transportation developed, the joint exploitation of wool and mutton was not possible. They add that the development of technologies that allow to switch tasks and vary the order in which parts are transferred is one of the main factors underlying the achievement of economies of scope.

Figure No. 1 shows the total cost surfaces of producing the same two goods, Y_1 and Y_2, prior and after the introduction of a new technology. Both cost surfaces reflect the total cost of producing either Y_1 or Y_2, or a combination of them. If only Y_1 or Y_2 are produced, then we have a conventional single-product cost curve on each horizontal axis. Cost surface C_2EF is the result of using 'old' specialised equipment. Producing a combination of goods Y_1 and Y_2 implies a cost penalty due to resetting and changeover costs and input waste. There is 'diseconomies' of scope, as reflected by the shape of the cross section connecting points E and F --i.e. the costs of making Y_1 and Y_2 separately is lower than producing them jointly (transray concavity).

Following the introduction of a 'new' cost saving technology, a new, lower cost surface C_1CD emerges. Total costs have fallen due to a reduction in factor and/or input costs for each individual good, as exemplified by the shift downwards of each good's cost curve. There is also an economies of scope gain. Producing both goods jointly is now cheaper than making them separately, as shown by the shape of the cross section linking points C and D (transray convexity).

Figure 1

The discussion thus far does not consider the impact of technical change on scale. Stevenson (1980), and more recently Stiglitz (1987) and Markowski and Jubb (1989), raised the possibility that technical change may also have a scale 'bias'. In Stevenson's (1980) view: "Such a bias would alter the range over which returns to scale of a given degree could be realized -- and thus possibly alter the output level at which minimum average costs could be attained." (pg. 163). Markowski and Jubb (1989) have extended this discussion to the multi-good setting and have explored some of the emerging scale and cost relationships.

To exemplify how technical change may affect scale, select a fixed combination of products Y_1 and Y_2, as that represented along the ray OR in Figure 1, and consider the cost behaviour as the scale of the resulting output bundle Y^* is varied --i.e. a 'slice' of the cost surface perpendicular to the Y_1, Y_2 plane and along ray OR. As along any particular ray output proportions do not change, by working with a 'composite' commodity Y^* one circumvents some of the problems posed by aggregating two different goods. Changes in the output of the composite commodity are of the same proportions of those of its individual components. Average unit costs for the chosen composite commodity Y^* can then be estimated at any point along this ray or 'slice', in the same way as in the single product case (ray average costs).

Figure 2 shows the average unit cost curves OT and NT_1 corresponding to producing the composite commodity Y^* under 'old' and 'new' technologies, with optimal scale points A and B respectively. As described above, there has been a reduction in costs but the scale of output has not been affected, as optimal scale remains on the Ay^*_1 line. Only when 'optimal' scale shifts to any point within the shaded area $OC_2Ay^*_1$, to the left of line Ay^*_1, i.e. at lower or equal unit costs than with the 'old' technology but lower volumes, is there scale reduction or 'de-scaling'. Point D in curve NT_2 represents one such case. A commonly mentioned example is the development of the electric arc furnace, which allowed the emergence of a number of steel mini-mills producing 100,000 tons of steel per annum as opposed to the conventional integrated mills, which required to produce several million tons to be efficient (Acs et al, 1990; Auty, 1992). Conversely, the introduction of a 'new' technology may lead to an increase in optimal scale or 'scaling-up'. In this case, lower average unit costs are achieved at higher levels of output than with the 'old' technology --the shaded area to the right of Ay^*_1. Point E in curve NT_3 illustrates this case. Stiglitz (1987) mentions the example of the chemical industry, where new more efficient plants have always larger capacities.

Figure 2.

In sum, the impact of technological change over costs and optimal scale is threefold. It may alter the share in unit costs of factors and/or inputs at any given level of output for any individual commodity. It may also affect the cost of joint production of goods, possibly allowing economies of scope. Finally, it may vary the 'technical' combination of factors or inputs, leading to lower or higher optimal levels of output.[2] Cost and technical factors together will determine if technological change has a 'neutral', 'de-scaling' or 'scaling-up' impact. For instance, one may face situations where lower optimal scales are achieved despite the existence of diseconomies of scope, due to the introduction of technologies that allow drastic reductions in capital and/or labour unit costs. Alternatively, increasing total capital costs may lead to situations where optimal scales can only be achieved at higher volumes of output.

Two final points in connection with the relationship between technological change, costs and scale. First, insofar as the cost axis may include change-over costs, production costs, intangible investments such as research and development and/or marketing, or a combination of them, and the output axis consider one or two goods produced in a multi-product plant or the same good manufactured in two different plants, the framework thus far developed would seem to be useful for analysing Scherer and Ross's (1990) three dimensions of scale: product --batch size--, plant --total plant output--, or firm --total firm production. The second point relates to the apparent nature of today's technological change. It is quite possible, and this will be the topic of the following section, that technical change may not only lead to the replacement of production facilities producing a range of goods by others producing the same. New production facilities may be capable of producing a much larger variety of products than before. Thus, in reality, there could be much more complex interactions and trade-offs between costs, scale and technology.

[2] It must also be pointed out that by allowing prices of individual goods to vary technical change may in addition affect marginal revenue.

III. THE IMPACT OF NEW TECHNOLOGIES ON MANUFACTURING INDUSTRY: THE 'MODERN TECHNOLOGY' LITERATURE VIEW.[3]

According to the 'modern technology' literature, advances in technology since the 1950s have radically transformed the nature of manufacturing industry. New technologies, particularly microelectronics and information technologies, have led not only to a series of developments in consumer electronics, but also, and perhaps more importantly, to the fabrication of more advanced design and manufacturing equipment.

The new equipment includes computer numerical control (CNC) machine tools, such as lathes or machining centres --which integrate drilling, milling and boring operations in a single machine-- used in metal cutting operations; 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 programs 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/RS), i.e. electronically controlled handling and storing devices; flexible manufacturing systems (FMS), the combination of CNC lathes and machining centres, load-unload stations, robots, automatic tool changing, electronically controlled vehicles to transport workpieces between stations, and a central computer for process control (Carrie, 1988); and computer integrated manufacturing (CIM) which integrates all design and manufacturing capabilities and other business data into a single system.

Together with these 'hardware' technologies, a number of new organisational techniques or concepts have also emerged (Best, 1990; Kaplinsky, 1984, 1991; Womack et al, 1990). These include Just-in-time (JIT), which refers to the practice of organising delivery of raw material, workparts and final products to each stage of production or to customers in a way that inventories and waiting time are minimised. Total Quality Management (TQM) implies addressing quality at all stages of production. It may involve the use of techniques such as statistical process control and/or the establishment of quality

3Under the 'modern technology' heading we are including a wide body of literature associated with terms such as 'flexible specialisation', 'post-fordism', 'new competition', 'toyotism', and 'systemofacture'. Their main concern is the analysis of the impact of NT on manufacturing industry and although they emphasise different aspects of it, they all coincide in the 'revolutionary' effect it is having on production processes. It includes, amongst others, authors in economics (Acs and Audretsch, 1990b; Acs et al 1990, Carlsson, 1989a, 1989b; Kaplinsky, 1984, 1990, 1991; Milgrom and Roberts, 1990; Morroni, 1991; Piore and Sable, 1984); engineering (Biemans and Vissers, 1991; Bolwijn et al, 1986), and management (Bessant, 1991; De Meyer et al, 1989; Womack et al, 1989).

circles, i.e. teams of workers constantly evaluating quality. Cellular/product manufacturing implies having physically reorganised the factory lay-out in cells dealing with parts of similar characteristics or in product oriented work centres. It includes partial reorganisation and experimentation with different lay-outs as there seems to be a wide range of possible lay-outs.

Most authors within this framework argue that the benefits of the new technological and organisational innovations can only be fully reaped when they are introduced in combination. To a large extent this is due to the complementary nature of NT: if the level of use of any innovation --or group of them-- rises, then the marginal return to increases in any or all of the remaining complementary innovations also rises. The introduction of, for example, CAD/CAM technology makes it cheaper to improve on products and design and introduce new ones more often. However, for the equipment to be fully profitable, an FMS technology which allows the production of a wider range of goods may be required, which in turn may only be worthwhile if a change in marketing strategy follows (Milgrom and Roberts, 1990).

It is also said that NT and associated organisational techniques have significant impact on scale and scope. At product level, it is argued that unlike 'specialised' old technologies, NT capacity to integrate diverse equipment and functions and to be programmed helps reduce minimum batch sizes --i.e. quantities of the same product treated in a certain process or sequence of operations-- by reducing setting-up times and costs. These include the costs of changing and adjusting machines with appropriate tools, resetting equipment, and/or readjusting transfer lines from a previous batch to a new one (Hoffman, 1989; Kaplinsky, 1984, 1990). Lower setting-up costs makes it economically feasible to produce diverse goods. In addition, by allowing production facilities to vary easily their product range and fully to use their equipment, NT lead to economies of scope (Bailey and Friedlaender, 1982; Baumol et al, 1988).

At plant level, it is asserted that NT are substantially shrinking the size of machinery and plants while, at the same time, making it possible for most capital equipment to be available in a wider spectrum of capacities, which, together with falling semiconductor prices, is drastically cutting the cost of capital equipment and allowing the emergence of smaller efficient production facilities (Acs et al, 1990; Acs and Audretsch, 1990a; Carlsson, 1989b; Gilder, 1988; Jaikumar, 1986; Kaplinsky, 1990; Rosenberg, 1988; Talaysum et al, 1987). It is also claimed that, particularly for continuous production, lower equipment costs could be possible from the application of economies of scale principles to the design and manufacture of a very large number of small plants or plant modules rather than to building fewer, larger plants. This would now be possible because of advances in plant design technology (Auty, 1992; Benson, 1989; Benson and Ponton, 1991; Stevenson and Walker, 1987). In batch production, Ayres (1991) and Ayres and Miller (1983) hold that there is potential for further capital cost reductions through the standardisation of programmable machine tools and robots. Hence, smaller, more divisible and cheaper equipment and plants will result in optimal volumes of output lower than with old technologies.

Critics, however, argue that there is no reason why NT should lead to reductions in plant scales (Alcorta, 1992, 1994 ; Bureau of Industry Economics, 1988a, 1988b; Markowsky and Jubb, 1989; Mody et al, 1992; Rhys, 1992). It is contended that physical sizes of equipment and plants should not be confused with economic sizes. While it is true that semiconductors, computers and some electronic products are undergoing 'miniaturisation' and that, by integrating, machines are occupying less space and therefore getting 'smaller', it does not follow that machines are also falling in capacity (Alcorta, 1992, 1994). NT may be faster, more efficient and reliable, and may be able to operate longer hours, thus expanding capacity. Also, by reducing setting-up times and expanding variety, NT may allow to increase total plant output even further, so that scale and scope economies at product level reinforce economies of scale at plant level. It does not follow either, that because equipment is physically smaller it costs less. Despite falls in the cost of microchips and computers and their increase in power, the cost of the production equipment that uses them may still be higher than the technologies it replaces (Alcorta, 1992, 1994). Indeed, this could be due to the more sophistication, complexity and integration of the NT, even after some degree of standardisation has taken place. Availability of equipment in smaller capacities would reduce plant scales only if equipment cost has fallen in line with capacity. Otherwise, it only means that smaller firms may have access to these technologies (Alcorta, 1992, 1994). In any case, given that 'greater divisibility' is mainly restricted to computers or electronic products and has hardly had any impact on production equipment, there is no a-priori justification to expect any significant 'de-scaling' trend in production. Finally, the capacity to design smaller plants has not been fully developed and is only a possibility for the future.

Furthermore, at firm level, NT may increase research and development (R&D) and marketing 'fixed' costs. R & D costs could rise because of the need for a considerable backlog of knowledge in, and the integration of, 'old' disciplines, including physics, chemistry, mathematics, electrical and mechanical engineering, together with 'new' ones, such as computer science and electronics, in the design and development of new products and processes (Mody and Wheeler, 1990). The increasing technical complexity of many products (Ayres, 1991), the 'never-before-seen' nature of some new products

(Kline and Rosenberg, 1986), the larger design efforts required to take full advantage of the more flexible and faster manufacturing capabilities (Goldhar and Schlie, 1991a, 1991b; Stalk, 1991), and the sizable investments in software and computer specialists necessary to link design, manufacturing and other functions of the firm (Bessant, 1991), are also pressing R & D costs upwards. Marketing costs could also rise because of the higher information requirements for selling and the growing advertising expenditures to communicate the availability of new products (Belussi, 1987, 1992). Whilst the net effect may result in 'scaling-up', as higher levels of output may be needed to amortise increasing R&D and marketing 'fixed' costs, Kaplinsky (1990) and Kline and Rosenberg (1986) argue that by becoming imitators, by focusing only on minor innovations, or by networking and sharing some overheads among firms, the impact of these costs on firm scale could be minimised.

IV. DIFFUSION OF NEW TECHNOLOGIES

1. Diffusion of NT in developed countries.

Diffusion of new flexible technologies in developed countries has proceeded rapidly in recent years. In 1976 CNC machine tools accounted for 21% of total metal cutting machine tools output, but by 1990 this share had risen to around 64% --Table 1. In 1989 CNC machine tools accounted for more than 70% of total metal cutting machine tool output in France, Germany and Japan, while in the US the share of CNC in total machine tool output was 97% (ECE, 1992). Nonetheless, despite this significant increase, CNC machine tools still constitute a relatively minor proportion of the total stock of machine tools, according to the Economic Commission for Europe (ECE, 1992). It was estimated that in 1987 only 11% of the total stock of machine tools in the US was CNC. Thus, it will not be until the end of the 1990s that CNC machine tools will dominate metal cutting.

Diffusion of some other NT has also proceeded apace. It is estimated that there were 1,200 FMS worldwide in 1989, with a growth rate in new installations of 20% per year (Haywood et al, 1991; ECE, 1992). The population of robots was around 460,000 worldwide in 1990, around 60% located in Japan, a six-fold increase over 1983 (ECE, 1992). Åstebro (1992) estimates that there were around 303,000 CAD 'seats' --a CAD system may have more than one workstation or 'seat'-- in 1986, a seventeen-fold increase over 1980. According to ECE (1992), the diffusion of these technologies has been accompanied by the introduction of JIT and TQM, although no figures are available on these organisational techniques.

2. Diffusion of NT in developing countries.

i. A note on methodology.

Before examining the data on the diffusion of flexible automation in sampled firms let us briefly review the methodology used for this study. One first choice was to concentrate on the engineering industry. Engineering was selected because much of the current debate on the impact of automation on scale and scope relates to this industry and, according to the literature, in no other industry has the impact of flexible automation been as pervasive, as most production processes and sub-processes and functions within firms have been affected (Freeman 1982; Freeman and Perez, 1988; OECD, 1988). Focusing on the engineering industry was also important for at least two other reasons. First, the industry is characterised by a diversity in equipment, processes and products, so firms have constantly to face choices between specialising or diversifying their product range and the underlying technology (Edquist and Jacobsson, 1988; Westphal and Rhee, 1983). Hence focusing on the engineering industry offered a unique opportunity for appraising the possible combinations and trade-offs between economies of scale and economies of scope. Second, the engineering industry has significant forward and backward linkages and is at the forefront of technological progress, as it is highly knowledge- and learning-intensive and provides equipment to all sectors of the economy (ECE, 1992; UNIDO, 1991). The emergence of cost efficient engineering firms in developing countries may, in turn, add to the building of local technological capabilities and long term development. To capture a representative distribution of sub-sectors within engineering, research was conducted in automotive components, capital equipment and machining services and mould production.

The study was conducted on six developing countries: Brazil, India, Mexico, Thailand, Turkey and Venezuela. Information available at the time suggested this was a representative sample of countries that had adopted NT. In Latin America, Brazil has a fairly developed engineering industry by developing countries' standards and research by Bortolaia (1992), Carvalho (1992), Fleury (1993), Ferraz et al (1992) and Porteous (1992) show increasing and sustained adoption of NT. From being a protected industry mainly oriented to the domestic market, it is slowly opening up to foreign competition and exports. Mexico was expected also to provide an interesting study case, as the engineering industry has recently received a large influx of foreign and local investment aimed at modernising the industry and entering the US market. The Mexican industry is one of the most open to foreign competition within Latin America. There was already some research and statistics on the adoption of NT in the engineering industry by ownership, firm size and sub-sector by Dominguez-Villalobos (1993), which could be used as a starting point. Neither the Brazilian nor the Mexican studies already done, however, shed any light on scale and scope issues, as all the effort had been put in finding the motives behind adoption. The third country in Latin America was Venezuela. Helped by a sustained inflow of foreign exchange from its oil resources, Venezuela has quietly been building its manufacturing base. Indeed, imports of machine tools have overtaken those of Argentina, have been sustained during critical periods, and are the eighth largest of all developing countries including NICs (UNIDO, 1991). Venezuela has carefully been opening up its industry to foreign competition.

In the Middle East, Turkey's engineering industry has been performing very well in recent years. According to ECE (1992), the index of engineering industrial production in Turkey increased by more than 46% between 1985 and 1990. Of all developed and Eastern European countries, only Austria and Ireland have performed better. The industry has been exporting metal-forming machine tools to more advanced countries and is, according to metal-cutting machine tool manufacturers in Europe, one of the most attractive markets in developing countries and has achieved a significant degree of technological capabilities. Another country that was expected to provide useful insights to the research was India. For years India had protected its engineering industry behind a wall of tariff and non-tariff barriers. Since the early 1980s import liberalisation has had a profound impact on the industry. Annual imports of machine tools were on average 23% higher in 1986-88 than in the previous six years and are estimated to have risen even further in more recent years (UNIDO, 1991). According to Jacobsson (1991), liberalisation may lead to an increase in the variety of products supplied both by the local engineering industry and by imports, but this may be achieved at the expense of losing procurement, R&D, marketing and finance scale economies and limiting the potential for own innovation capabilities. Finally, in the Far East, Thailand was studied. Research by O'Connor (1989), UNIDO (1991) and Watanabe (1993) point out at an emerging hi-tech engineering industry producing components for automobile, motorcycle, agricultural machinery and electrical appliance manufacturers, both for the local market and exports. Indeed, Hitachi has recently relocated production of electric motors for its machine tools from Japan to Thailand.

The research was based on firm case studies made by local consultants. Case studies have the disadvantage of their limited value for generalisation, as it is not always easy to distinguish results which are specific to the case under scrutiny from those that reflect the wider collectivity. A case study approach, however, is appropriate for this type of study because the diffusion of NT is a recent phenomenon in developing countries, so statistics or surveys are either not available or too expensive to generate. It is suitable because certain issues, like those of technical change and technological capabilities, can only be comprehended through the study of the internal workings of firms, the 'microcosmic realm' (Westphal et al, 1990). To the extent that, in developing countries, technical change may be, in addition, restricted to a few firms and accurate and detailed data from them was required for sensible conclusions to be reached, opting for a case study approach seemed particularly pertinent. A case study approach was also germane because it was necessary to have precise knowledge of the technologies being adopted and the extent of their adoption in order to perform meaningful international comparisons.

A sample of a minimum of 8-10 firms that had adopted flexible automation was selected in each country for in-depth interviews. Thus the overall sample amounted 60 firms in the six countries. The size and ownership distribution of firms in the engineering industry in each country was taken into account. In addition, interviews were conducted with national and international machine tool manufacturers, local representatives of machine tool producers, importers and traders of new equipment, specialist engineers and technologists, academics working in the field of flexible automation and industry associations.

ii. Aggregate

Figures on diffusion of flexible automation for developing countries are not as readily available as for developed countries. Research by Watanabe (1993) shows that between 1980-1990 exports from Japan, Germany and United States to developing countries amounted to 25,809 metal cutting CNC machine tools, of which more than half were accounted for by South Korea, Taiwan and Singapore, 12% by India and China, roughly equally divided, 7.5% by Mexico and 3.8% by Brazil.[4]

Our own research shows that the use of microcomputer-based flexible automation in developing countries began in a significant way in the second half of the eighties. Although some imports of CNC machine tools had taken place prior to that, these were sporadic and, according to some suppliers, it was not clear that these machines were effectively used. By the mid-eighties some firms in our sample had purchased a CNC lathe or a machining centre but their use was not widespread within firms. It is only in the second half of the eighties, and especially towards the end of the decade, that adoption of flexible automation began to spread throughout industry and within firms. In India output of CNC machine tools increased from 65 units in 1985 to 683 units in 1991. In Turkey imports of CNC machine tools rose from 471 units in 1989 to 3,601 units in 1993. In Venezuela, use of CNC machine tools doubled from 1988 to 1993. Taking our sample of firms as a whole, we found that use of CNC machine tools increased by between 200% and 400% from 1988 to 1993, implying an annual rate of growth of 20%-40%.[5] To the extent that diffusion of CNC machine tools in developed countries

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[4]Numerically controlled machine tools include three types of machine tools. First, what initially was known as numerically controlled machines, where information to produce a particular part was put into a punched or magnetic tape which was then fed into the control unit. These machines were developed in the 1950s. Second, minicomputer-based machine tools, where the control unit began to be based on minicomputers. This generation of machine tools started to diffuse widely in the early 1970s. Third, microcomputer-based machine tools, where the control unit became a microcomputer. These machine tools started to appear in the market in 1975. These are today's CNC machine tools (Edquist and Jacobsson, 1988).

[5]The annual rate of growth of the stock of CNC machine tools was 16% in the United States between 1978 and 1985 and 18% in the United Kingdom between 1976-1983. The rate of growth of the stock seems to have been even higher in the late eighties but with the exeption of Japan decelerated between 1990-1993 in most developed countries (ECE, 1992; Edquist and Jacobsson, 1988).

started in the late seventies, there would seem to be an approximate ten year lag in their use by developing countries.

Despite the rapid growth in use of CNC machine tools by developing countries since the late eighties, the stock of CNC machine tools still remains low as compared with that of developed countries. In the 1992-1994 period there were 5,000 units in India, 22,471 in Mexico, 9,491 units in Turkey and 400 units in Venezuela. The stock of CNC machine tools amounted to 103,000 units in the US in 1983, 118,000 units in Japan in 1984, 47,000 units in the UK in 1987, and 20,000 units in Sweden in 1989 (ECE, 1992; Edquist and Jacobsson, 1988). If stocks of machine tools are an indicator of technological differences between countries, then developing countries still have some catching-up ahead of them.

iii. Sample

Table 2 shows the diffusion of flexible automation by type of equipment in sample firms. The most widely used equipment are metal cutting CNC machine tools and, within them, CNC lathes. CAD and CAM were also used in all countries although their use was heavily concentrated in firms in Brazil and Mexico, most of which had more than one 'seat' each. In most cases CAD/CAM is used by sample firms to design and manufacture jigs and fixtures, although some firms also use them for product adaptation. Robots were in use in Mexico and Thailand, mainly as attachments to CNC machine tools for automatic feeding. In Thailand robots were also used in material handling applications, for transferring workpieces between stations and in arc welding applications. FMS, combining machining centres, were used by four firms in Brazil and Mexico. The Brazilian firm using the FMS claimed it was one of a few of its kind in the country. Computerised production control for production planning, scheduling and routing was in use by Brazilian, Mexican and Venezuelan firms.

Using the number of workers per CNC machine tool as an indicator of the degree of automation shows that Mexican firms are the most automated, irrespective of size, industry or ownership (see Table 3). Venezuelan firms are the next most automated with nearly double the number of workers per CNC machine tool than their Mexican counterparts. The relatively high level of automation of small locally-owned Venezuelan firms would seem to account for this result. Thai mould manufacturers and machining services firms and Turkish capital equipment firms are notoriously less automated than their equivalents in the other countries of the sample. Brazilian and Indian firms are among the least automated, although the Indian ratio of workers per CNC machine tool more than doubles the Brazilian ratio. Whilst in the case of Brazil the relatively low degree of automation seems to be the result of heavily manned large autocomponent firms, in the case of Indian firms low automation seems to be a more accross the board phenomenon.

Table 4 shows the density of automation by firm size, industry and type of ownership. In this case density of automation refers to the share of machining that is accounted for by CNC machine tools. Measuring the extent of automation in this way has the advantage that it focuses exclusively on the production stage that is affected by the use of CNC machine tools. Hence, it is a precise measure of the degree of automation. A share of over 75% can be considered as near total automation whilst a share equal or under 25% can be seen as minimal automation.[6] Small size includes firms with equal or under one hundred workers while large size includes firms with more than five hundred workers. Autocomponents includes manufacturing of products such as front and rear axles, brake disks and systems, shock absorbers, transmissions, piston rings and cylinder linings, fuel systems and engine bodies. General capital equipment includes manufacturers of oil and water valves, pumps and electric motors. Other consists mainly of producers of moulds and firms providing machining services and some other firms that could not be classified elsewhere. Foreign ownership consists of firms that are majoritarily owned from abroad. Foreign participation includes firms with a minority foreign stakeholding. Locally owned are firms fully owned by local residents.

One first conclusion that emerges from this table is that large firms are not highly automated, while small firms are. Typically large firms in the sample are older, with significant investments and a long experience in old technology. Scrapping of capital equipment implies major disruption in terms of production process, labour organisation and skill requirements. With superior information, a more organised process for searching and selecting new machines, and given a context of very high uncertainty, as that of developing countries, large firms seem to be taking investment decisions carefully and adopting new technologies gradually. One of the large Brazilian firms included in the study said that it was considering a major upgrading of its technology but it would do so in the context of building a completely new production line for a major product change. The only large firm that is highly automated is a long-lived Mexican manufacturer of glass-moulds and part of a large glass manufacturing conglomerate with a substantial share of the world market in glass containers.

Small firms typically are much younger and many of them started their operations with new technologies. Unlike large firms, whose production processes may include foundry, forging chemical

[6]Density of automation figures were directly provided by firms or estimated on the basis of stock of conventional, automatic and CNC machine tools, their relative efficiency and total output.

treatment and large scale assembly, small firms focus mainly on machining, although some simple assembly occasionally takes place. Some are spin-offs by engineers, managers and/or skilled workers from large companies or are members of large local industrial conglomerates to whom they are today supplying very specialised components or machining services. Thus, at least initially if not continuously, they have drawn on the information and resources available in large firms and have started with a relatively captive and predictable market, but often on condition that they adopt flexible automation. This was the case of Comet Ltd. and K.R. Industrial Products Ltd. in India. These companies were set up in the early 1990s equipped with CNC machine tools in order to produce components for TELCO, India's largest lorry manufacturer. They are located in an industrial estate near TELCO and sell exclusively to TELCO. Comet Ltd. and K.R. Industrial Products Ltd. stated that they would not be acceptable to TELCO as suppliers without the use of CNC machine tools.

A second conclusion is that producers of moulds and machining services firms are more automated than their capital equipment and automotive components counterparts. Mould production is one of the most demanding activities within engineering because of the difficulty in machining, arising from the uniqueness of each mould and the intricacy of design. Machining services firms manufacture the widest product mix possible within the industry and normally face very unusual and precise demands. It is crucial for these firms to deliver the best possible quality to be successful, something that can only be achieved with the latest technologies. Some of these companies are operating in foreign markets and therefore having to meet the highest international standards to remain in business. One of the Venezuelan firms providing machining services for the oil industry, which sometimes involves manufacturing vital and security parts for oil rigs and wells, is permanently assessed by Petroleos de Venezuela (PDVSA), the Venezuelan state oil company. Alpha, the Mexican glass-mould manufacturer we referred to earlier, not only has the most up-to-date manufacturing equipment but has its CAD/CAM linked via satellite to its main customers, so that their clients can, on-line, give precise instructions and introduce the exact modifications required.

A third conclusion is that foreign owned firms do not seem to be more automated than local ones, although this conclusion must be taken carefully as there were only few majoritarily foreign owned firms in the sample. This was a surprising finding, as one would expect that foreign companies, which in all cases were subsidiaries of large German and US multinational corporations, would have access to better information and managerial and financial resources and therefore use more advanced technology vis a vis their local counterparts. However, foreign firms in the sample are mostly car component manufacturers that have been in operation between 20-40 years, meaning that they were established at the height of import-substitution and of efforts to develop a local car industry. They are firms that came attracted by the less demanding local market and made major investments in technology some time back and therefore are 'locked-in' to old technologies. In addition, although quality standards are getting stricter in the car components industry, they are still not as exacting as in mould manufacturing or machining services, thus allowing component firms to pursue automation gradually and selectively, focusing on critical parts first. Some firms have started recently to invest in materials research and new product design and to integrate more closely with assemblers, all of which may result in additional changes in production technology at a later stage. A case in point is a Brazilian-based US owned manufacturer of mechanical transmissions for light and medium lorries. Established in Brazil in 1953, it has built in Sao Paulo one of the largest plants of its kind in the world but with a density of auutomation of only 20%. The company started to invest significantly in flexible automation around 1986/87 and soon after installed a four machining centre FMS which is used for machining bodies of its newest transmission. Since, investment in new machines has been exclusively oriented towards flexible automation and the rate of acquisition of CNC machine tools has doubled.

Locally owned firms and majoritarily-locally owned joint-ventures seem to be resorting to flexible automation as a means of achieving domestic and international competitiveness. In the case of joint-ventures, most country studies pointed out at the foreign partners as having a significant influence in the level of use of CNC machine tools locally. In the case of local firms producing for original equipment manufacturers (OEM), the main client had also a significant say in the level of automation of its suppliers. In most cases this implied higher rather than lower automation, although we found one firm where the opposite was recommended.[7] At CMI, a Thai producer of car components, following the introduction of four machining centres the manager decided to add a robot as a machine server because of the weight of some of the casted parts, up to 40 kilograms. The Japanese client, apparently, was not confident CMI could handle the complexities of introducing a robot and insisted on manual loading. Finally, in the case of local firms producing for local markets, they are also being forced to automate in order to withstand foreign competition arising from more liberalised markets, although we will return to this point later.

Summing up, diffusion of flexible automation has proceeded rapidly in developing countries in recent years although there is no evidence of the technological gap closing. Of the range of flexible automation technologies it is CNC machine tools, and within them lathes, that are diffusing in

[7] It is paradoxical that while local firms are being asked to automate by multinational corporation clients foreign owned firms are not.

developing countries. By far the country in our sample that has benefitted most from the new technologies is Mexico, followed not so closely by Thailand and Turkey. Within sample countries, small firms seem to be more automated than large ones mainly because of their age, lack of commitment to old technologies and the support received from large firms. By helping small firms large ones can postpone undertaking major investments themselves. Mould and machining services firms are more automated than car components or capital equipment firms because of the exacting quality conditions their industry faces. Finally, local firms are more automated than foreign ones because of the demands exercised by foreign partners or clients or by the more competitive conditions faced in local markets.

iv. Flexible automation and new organisational techniques.

One of the most widely held views within the modern manufacturing literature is the complementarity of flexible automation and new organisational techniques or concepts. It is pointed out that only if both are adopted in combination can the full benefits of automation be reaped. In this section we will look into whether flexible automation and organisational techniques or concepts are actually being combined and the reasons for it.

Tables 5 and 6 present the diffusion of new organisational concepts by density of automation and by firm size, industry and ownership. Apart from the organisational concepts or techniques mentioned earlier, we have considered two other areas of organisational change. International Quality Standards involves having obtained or being in the process of obtaining an international quality certificate such as the International Standards Organization's (ISO) ISO 9000 or Ford's IQ 101 or being able to comply with official European, United States or Japanese product standards. This is not one of the new organisational techniques according to the modern manufacturing literature but it is a means some firms use to test themselves in terms of quality. Working practices reorganisation involves the reduction of hierarchical levels, redefinition of job posts and functions, changes in pay practices and enhanced responsibility for shopfloor workers. The adoption of any of these changes in working practice was considered sufficient to include a firm among those reorganising working practices.

A number of points regarding the combination of flexible automation and organisational concepts. First, none of the organisational concepts had been diffused to more than half the firms in the sample, while 18 firms had not adopted any of the organisational concepts. This suggests that organisational techniques are not as widespread in developing countries as one would expect given the alleged complementarities.

One possible explanation recently put forward by Fleury (1995), Humphrey (1995) and Meyer-Stamer (1995) is that implementing organisational change is complex and difficult because it involves modifications in managerial structures and working practices that have been in use for a long time. Only firms that have already been experimenting, for instance, with quality control and have the "basics of production organization and cost control in place" (Humphrey, 1995; pg. 156) will be capable of implementing organisational change. Change is a learning process and firms must be willing to undertake it. Under monopoly conditions, in long-protected markets or, one would add, in fast expanding markets where whatever is produced is accepted by consumers, firms just do not feel the need to reorganise. Indeed, this seems to be the case of many of the Thai firms in our sample which, facing increasing demand from exports, particularly to Japan, have responded by adding productive capacity rather than looking into ways of reducing any slack existing in production and improving productivity through the adoption of some of the new organisational concepts.[8]

There may be human resources constraints to the adoption of the new organisational techniques (Kaplinsky, 1995). The successful introduction of these techniques increasingly requires an educated labour force capable of understanding the underlying technical processes. It may also require sustained training in order to develop the new skills that are necessary to implement the new technologies and organisational techniques. But the educated workforce and the resources to invest in training may not be available, an issue we will return later to.

The alleged complementarities raised in the literature may not be as low-cost or costless as many authors would seem to assume (Hoffman, 1989; Kaplinsky, 1994; Posthuma, 1995). While it may be true that organisational change may be 'divisible', in the sense that one can introduce the amount of JIT, quality procedures or new working practices that can be afforded, it nevertheless still implies a considerable monetary cost. In preparing this research project we visited a car component manufacturer in The Netherlands which was building a completely new plant for manufacturing dashboard panels. The plant had been equipped with the latest automation technology, a carefully studied lay-out and was introducing most, if not all, new organisational concepts. To do so, workers had been hired six months ahead of what they would normally be when starting a new plant in order to

[8]Meyer-Stamer makes the interesting point that there may be different paths to competitiveness, some of which may not require organisational change at all.

get them acquainted with the technology, despite them being fully qualified workers, and involved in quality discussion groups. Quality circle meetings were taking up to three days a week and most workers participated. Whilst management had no doubts about the long-run benefits of this approach, it was also fully aware that the financial cost in the short-run was equivalent to six months wages. Preparing the new lay-out had required two years' work of a specialist engineer.[9]

Lack of adoption may also be the result of the state of the infrastructure in developing countries. JIT requires a sophisticated and efficient transport system that is rarely available in developing countries. Some of the countries studied not only have no developed transportation system but also lack basic services such as electricity or water. In a context where management does not know whether the factory is going to have electricity the next day or week, or whether raw material delivery is going to be on time or a month late, priorities have to be organised on a different basis. Inventory holding may make a lot of sense under these conditions. Otherwise the just-in-time may result in just-without-anything.

A second point regarding the combination of flexible automation and organisational change
is that the degree of complementarity would seem to vary according to the type of organisational technique. Take the case of changes in lay-out. As was pointed out before, one of the most distinctive characteristics of the new technologies is that they can integrate diverse equipment and functions into a single machine. A CNC lathe can perform turning operations at both ends of a rod and perform simple drilling, tapping and boring operations on the same rod. Drilling, milling, tapping and boring operations can be performed in a single machining centre. With conventional technologies, machining a gear box casing and a shaft for the gear box required around 20 operations in some 12-15 different machine tools. Bringing the 12-15 machines together in a cell or product type lay-out would demand considerable space and would be, considering that more than one shaft and gearbox casing has to be produced and that other parts need also to be produced, totally unmanageable.[10] Under these conditions, a functional lay-out for the factory would make considerable sense. With CNC machine tools both the gearbox casing and the shaft can be produced with two machining centres and one lathe. And so can some other parts for the gear box. Under such conditions, bringing together the three machines and a gear cutting CNC machine tool is enough to produce the whole gearbox and may be the most efficient, if not the only way, of organising the factory and thus hardware and organisation are

[9]Relative prices may also play a role here. Where interest rates are low and land inexpensive, then pressures to introduce JIT and reduce inventories may be lower than where the opposite is true.

[10]When the number of conventional machines involved is small, an arrangement along cellular/product lines may be feasible.

highly complementary. The fact that the majority of the firms adopting this organisational concept is highly automated would seem to corroborate this.

TQM and JIT would seem to be relatively independent of the level of automation. Consider the case of TQM. In essence, it consists of quality checks being instituted at each stage of the production process instead of the more traditional checking of final producs for defects after they were manufactured. Quality becomes the reponisibility of each individual worker and not of the quality department anymore. To equip workers with the capacity to judge the quality of each part or product they are informed of the characteristics of the product and the level of quality expected at each stage and they participate in discussions with other workers and staff to identify possible sources of problems, problems that are already emerging and ways of solving them collectively. Because of errors being found at an early stage and individual responsibility identified, this approach leads to significant reductions in defect rates. Obviously, TQM concepts can be adopted irrespective of the level of automation and may be adopted even with no automation, as Kaplinsky's (1994) review of the introduction of 'Japanese management techniques' in Brazil, the Dominican Republic, India, Mexico, South Africa and Zimbabwe shows. Our own data showing no significant difference on diffusion of JIT and TQM by level of automation would seem to suggest this is indeed the case.

A third point is that organisational concepts seem to be diffused mostly among large and medium size firms. This finding is remarkable in the light of small firms being among the most automated in the sample. This may be due to the fact that small firms focus mostly in machining and have a small number of machines, so that there is neither the need for a sophisticated production lay out nor for ellaborate quality control procedures and practices. Being small eases face to face contact and therefore should lead to better communication. Production takes place as quickly as possible anyway, as fast response time and providing exactly what the client requests is one of the key competitive characteristics of small firms (Pratten, 1990). Large firms, by contrast, have to install procedures and develop practices that will allow them to ensure quality and rapid delivery.

Organisational concepts seem also to be more diffused in the autocomponent industry than in capital equipment and other. One plausible explanation is that, as competition in the automobile industry gets fiercer and final assemblers increasingly move towards JIT production and get stricter with their quality controls, autocomponents firms are being dragged into adopting the same techniques to remain in business. JIT techniques do not involve only a single firm but all levels of component manufacturers for it to be fully effective. Note also that insofar as car components firms are the less automated in the sample, they seem to be substituting, rather than complementing, hardware and organisation. The same would seem to be true for foreign owned firms, which have low levels of automation but high levels of adoption of organisational techniques.

iv. Factors underlying diffusion.

Two sets of factors emerged as underlying the diffusion of flexible automation and organisational concepts in developing countries. At the aggregate level changes in the trade regime and higher aggregate demand were among the most significant.

Growing foreign trade liberalisation in many developing countries during the eighties led to lower CNC machine tool prices and their wider availability in producer countries such as Brazil and India. Actual and potential users increasingly found imported CNC machine tools better in quality and sophistication, available at affordable prices and thus were attracted to invest in them. Brazilian firms were adamant about pointing this factor as key in their decision to acquire CNC machine tools. Trade liberalisation also increased the level of competitiveness in engineering both through the direct competition of foreign goods and, in some cases, through a reduction of the local demand for engineering goods resulting from the closure of factories and the reduction in real incomes that have accompanied some of the trade liberalisation processes. Liberalisation also had the effect, particularly in the vehicle assembly industry in India, Mexico and Turkey, of attracting additional foreign investment from vehicle producing multinational companies.

Countries like India, Mexico, Thailand and Turkey also benefitted from an increase in aggregate engineering goods demand resulting from both local and foreign sources. Domestic demand for vehicles increased sharply during the second half of the eighties in India, Mexico and Turkey. Production of cars and commercial vehicles rose from 114,000 units in 1980 to 355,000 units in 1991 in India, from 490,000 units in 1980 to 989,000 units in 1991 in Mexico and from 51,000 units in 1980 to 242,000 units in 1991 in Turkey (Jenkins, 1993). A larger demand for vehicles slowly traduced into a higher demand for components because of local content rules, lower local unit costs and increasing domestic technological capabilities. Mexico also profited from increasing demand due to its participation in the North America Free Trade Agreement (NAFTA), which has given a significant boost to engineering exports, particularly to the United States. By 1990, Mexico was exporting US$2.6 bn worth of vehicles and US$1.2 bn worth of engines. Thailand, in turn, has also found a large outlet for its engineering products in Japan, including auto and motorcycle components, electrical motors, water pumps and sanitary fittings.

At the micro level reasons of quality, flexibility, machine productivity, labour costs, lack of skilled labour, and lower production costs and lead times were at the basis of the diffusion of the new technologies (see Tables 7 and 8).

Quality was the most important reason for the diffusion of the new techologies in developing countries. Around 90% of the firms gave this as one of the reasons for adopting and was at the top of the list of importance in most of them. But quality meant different for different types of firms. For autocomponent firms the key dimensions of quality are repeatability and durability. Except for four autocomponent firms in the sample which had transfer lines, the predominant technology in use by firms in developing countries prior to the diffusion of flexible automation was conventional machine tools accompanied on occasions with some automatic lathes and/or drills. This meant that obtaining consistency accross the same part depended on the capacity of the machinist to perform the same operation in exactly the same way throughout the day. This was obviously not posible and, as a result, numerous defects emerged, most of which normally went undetected. Add up the defects of the many parts that make any autocomponent and the defect rate at the end of the line was exceedingly high. In the case of Venezuelan autocomponent firms it ranged from 6%-13% of all final goods. With CNC machine tools and TQM this is no longer the case. Consistency of machining accross the same part can be guaranteed without too much loss, if any, of the manipulation capacity that a human hand gives. It is also easier to comply with pre-set tolerances and specifications. Hence, developing country car component firms' interest in adopting CNC machine tools.

For mould producers and machining services firms quality means precision, as their key techno-economic problem is being able to manufacture complex parts with a high degree of accuracy. The predominant technology in use by mould producers and machining services firms prior to adoption of flexible automation was conventional machine tools, even more than with autocomponent firmms. Achieving the shapes and tolerances required depended on the skill of the machinist and the relatively simple measurement instruments that went together with conventional technologies. Mistakes occurred often, scrap rates were high and the more difficult parts took a long time to be produced. CNC machine tools allow to machine to the finer of tolerances required without human intervention in the actual cutting. The operator limits itself to setting the required parameters in the control, some of which have user-friendly menu-driven software. If a CAD/CAM programme or terminal is available, the exact design of the part and the parameters for machining can be directly transferred to the machine tool, reducing even further the role of the machinist. Cutting becomes extremely precise, mistakes are minimised, material and time saved and the information can be stored for future use.

Flexibility refers to the capacity to produce a single product or range of products in speed or quantities that correspond more closely to changes in demand or to alter the product mix by introducing new products or modifying the properties of existing ones. Machine productivity relates to the need, expressed by several firms, to machine more output per unit of time. Reduction in lead times alludes to the desire of some enterprises to reduce the period from the placement of a manufacturing order to the moment the product is ready for delivery.

Achieving flexibility is important for autocomponent firms because of the way the car industry is organising today. Around 69% of the autocomponent firms in the sample gave flexibility as a key reason for the adoption of new technologies. As final assemblers increasingly introduce JIT techniques, they try to push inventories down to their first tier suppliers, which in turn also introduce JIT and push their inventory to third tier component suppliers, and so on and so forth. In the end, it is expected that all firms involved will minimise inventories and so reduce the costs of carrying stock and the opportunity cost of having capital tied down in production.[11] The Dutch dashboard manufacturer we mentioned earlier said that Ford had started a system whereby, depending on the part, they could request parts from them with two hours, one day, one week and one month's advance notice. Hence, component firms need to be able to respond very quickly to the changing demand of their customers.

In capital equipment and machining services the key problem to be addresssed was different and therefore reasons of machine productivity and reduction of lead times were more important. Before the new technologies were introduced, manufacturing of any product involved selecting the individual machines, 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

[11]For problems with the implementation of JIT in the car industry see Rhys (1991).

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, producing was extremely complex and considerable time lost, a 'nightmare'. In practice, with old technologies, capital equipment factories and machining services firms were very disorganised and inefficient.

Labour related reasons for adoption of new technologies such as reduction of labour costs or compensating for lack of skilled labour were also mentioned by firms. Reduction of labour costs was important in Turkey and Thailand, where increasing real wages were a serious concern in firms. In the case of Turkey, the government had granted wage increases to manufacturing workers that had resulted in real wages hiking in more than 40% in the late eighties. Lack of skilled labour had been particularly acute in the mould and machining services industry in Mexico, Thailand and Venezuela. During the seventies and the early eighties Venezuela had obtained skilled machinists from neighbouring countries, particularly Colombia. By the late eighties, however, after having saved for some years and with the prospects for work improving back at home, many of the Colombiam workers started to return to their country, creating a serious shortfall of skilled workers in Venezuela.

Finally, around one-third of the firms also pointed out at the reduction in unit costs as a key objective behind their adoption of new technologies. Throughout engineering the competition was getting tougher and, with an increasing number of firms being able to deliver similar quality quickly, price competition was becoming a crucial factor as well. Interestingly enough, seven of the Mexican firms said that selling prices had fallen by between 15%-40% during the last few years while six Venezuelan firms pointed out at reductions in prices of engineering goods of 30%-75%. Profitability had also fallen despite some reduction in unit costs, with all but one of the Mexican firms that gave figures for profitablity declaring reductions of up to 50%.

V. SCALE AND SCOPE.

1. Changes in product scale.

Batch size reduction or 'descaling' is one of the main claims of the modern manufacturing literature and a desirable objective in itself because it reflects 'sensitivity' to the market (Kaplinsky, 1990; 1995). So, is batch size falling in developing countries? To address this issue firms were asked about changes in batch size with old and new technologies. Tables 9 and 10 show the results of our interviews by level of automation, firm size, industry and ownership.

Out of 44 firms that gave figures for changes in batch sizes in 43% batch sizes were reduced, in 41% there had been no change and in 16% they had increased. There were some indications that increases in batch sizes were associated with the level of automation, but the number of firms involved was too small to reach a firm conclusion. No change or increase in batch sizes were prominent among small firms, among mould manufacturers and machining services firms and among firms that had stated they were acquiring new technologies to increase machine productivity. Thus, the evidence suggests that the diffusion of new technologies does not necessarily lead to reductions in product scale.

Batch size depends on a number of factors. The size of demand, delivery schedules and availability of castings and forgings were commonly mentioned factors influencing batch size. The size of demand was evident in the case of Indian and Venezuelan firms. An Indian valve producer calculated its batch size on the basis of the monthly demand of each type of valve. Small, standard valves of high demand were produced in large batches while large and/or specialised valves, some of which were custom made, were produced in small batches. A Venezuelan monopolistic manufacturer of standardised household gas valves increased its batch size fourfold following a sharp rise in the demand of its products. Indeed, this manufacturer was dedicating all its CNC machine tools to the manufacture of a single product, albeit with variations in the size of the gas valve. On the whole, if batch sizes were too small or too large with regard to demand they were adjusted to fit it better.

In the case of some car component firms the batch size was largely determined by the delivery schedules insisted upon by the final assembler. Before, automobile manufacturers use to place bigger orders which resulted in larger batches being manufactured. Today, final assemblers have reduced the time-span between deliveries as part of their JIT strategies, causing suppliers' batch sizes to fall, as in the case of some Mexican firms where batch size decreased from several thousand units to around one hundred units.

Indian firms also pointed out that the availability of castings also affected batch sizes. Good quality castings and forgings were available often only in small numbers so firms had to keep this in mind when choosing batch sizes. Also , their supply was erratic and often firms were forced to run smaller batches than desirable.

It must be stressed, however, that there are still some limits to the reduction of batch sizes. Producing a new batch requires investing in fixtures, jigs, tools and system planning which may be unprofitable if the batch is too small or the selling price too low. Some car component manufacturers in Mexico had arranged for customers to pay for jigs and fixtures. Another Mexican firm operated with a 'rule of thumb' which stated that investment in jigs and fixtures should be no greater than 7% of production costs, otherwise the part was not produced. In fact, the research found that the use of rules of thumb to determine batch size was quite common among firms in developing countries. One Brazilian firms used as its 'rule of thumb' to produce at least three months of sales while another had a minimum batch of eight days for each ten hours set up. In Turkey, many firms operated with batch sizes equivalent to one day production because machines were preferred to be adjusted and programmed in the morning and used continuously through the second and third shift if necessary.

2. Changes in product variety or scope.

As predicted by the literature, the scope of products increased among most firms in the sample which provided data. Tables 10 and 11 show the number of different final products and product families, ie. all main types of final products, and the number of different parts machined, ie. different parts and components that enter final products.

Product variety increased accross all levels of automation, firm sizes, industries and types of ownership, although it was slightly more pronounced among auto-component and domestically owned firms. In the case of car component firms the adoption of NT has led to a wider product mix, spurred by lower setting-up times and the flexibility of the NT, the reduction in the life cycles of many vehicles and the demands of final assemblers. A Mexican car component manufacturer duplicated the number of brake models to 180, raised the number of shafts from 5 to 13 models and the number of axes from 42 to 403 models. Brazilian transmission and piston ring manufacturers launched more new products since the adoption of new technologies than they had since their establishment in the 1950s. In capital equipment manufacturing, mould producing and machining services product variety was always a feature but firms are moving now from a rigid, catalogue-based product mix to a more flexible customer-oriented supply of goods and services. Giving the customer exactly what it wants has become a distinct competitive advantage in these industries.

It is worth stressing, that while there are clear indications of increasing product variety, not in every case more variety means new products. In Mexico two firms producing car components stated that their figures on product variety include a combination of some new products with variations of old ones. For most of the other car producers it included mostly variations in dimensions of old products. The two firms which had developed new products also said that developing completely new products required significant efforts in product development. Before they had copied designs from other manufacturers but as soon they started developing their own products they had to start their own engineering department and linked closely to car assemblers. Thai firms in all industries made a similar point. They said that new technologies greatly facilitate the introduction of new variants of the same product, and that it was particularly shifting into product ranges requiring higher levels of precision but that with few exceptions the introduction of new products had not been usual.

A second issue that emerged when analysing product variety was the increase in vertical integration. Together with the figures on product variety we obtained data on changes in the number of parts or components manufactured in our sample firms. Most of the firms that showed increases in product variety also had rises in the manufacture of the parts and components that were part of those products. But, more importantly, the rate of increase in manufacture of parts and components was much higher than that of new products. Considering that not all the 'new' products were so but were varieties of old ones and on the assumption that the number ofparts and components has not change significantly one can conclude that firms are integrating vertically into the production of their own parts and components.

Indeed many firms stated this openly. With machining productivity increasing and low capacity utilisation, issues we will return to later, firms had reduced subcontracting and were taking on themselves the production of all but a few of the main parts and components. Thai firms declared that they were progressively integrating backward because they could now produce some of the more complex components which before they use to import or source from other domestic firms. The trend in India, Mexico, Brazil and Turkey was alo towards vertical integration.

In sum, although new technologies have resulted in some increase in scope it has mostly led to variations of new product and vertical integration. Producing completely new products would seem to require product innovation capabilities which were beyond the majority of the firms in our sample.

3. Changes in plant and firm scale.

Turning to the impact of new technologies on scale and optimal scale our evidence shows a very different picture from that presented in the literature. To begin with more than 90% of the firms that furnished us with figures on changes in scale of output or production capacity showed increases in scale, with one third more than doubling output or capacity (Table 12). Eleven Indian firms and ten Thai firms although not furnishing figures also stated that with new technologies scale was increasing. Therefore, a total of 49 out of 51 firms that addresed the question of scale said that it was increasing. Two firms that had more than one plant stated that scale had increased in all of their plants. One of the two firms, from Venezuela, that claimed scale reductions was having severe labour problems and had started a process of divesture.

An increase in scale is not, however, enough to conclude that optimal scale have also increased. It is thus necessary to find out whether scale has increase at lower or equal unit costs. Although unit costs figures were difficult to get some firms gave us the data or indications of the trends in unit costs after the adoption of the new technologies.

Table 14 shows that out of the 32 firms that provided unit costs figures in more than 70% unit costs had not changed or had decreased. Actually in the great majority of firms unit costs had fallen. All of them were firms where scale had increased. Firms where unit costs were higher stated a number of reasons for such a result. One Brazilian firm manufacturer of oil valves which had increased its output but at higher unit costs said that the higher costs were partly the result of the better quality in its products. There was now more capital as measured by the number of machining operations performed in each product and more skilled labour per ton of output. Had the number of operations and the input of skilled labour kept at the same level as with old technologies unit costs would have fallen. In addition the firm was facing a large degree of unused capacity which was further pressing unit costs upwards.

Other firms that had seen their unit costs increase also mentioned the problem of low utilisation rates. A Mexican machining subcontractor whose unit costs increased by 15% was operating at 70% capacity while a Turkish firm that saw its unit costs increase also by 15% was operating at 60% capacity. These firms stated that at higher utilisation rates unit costs would have actually fallen because of the very high fixed costs of the capital equipment. In the case of firms that actually had reduced their unit costs there were also problems of low capacity utilisation. Brazilian firms were operating at an average 50% capacity because of sluggish domestic demand. Mexican firms were operating at an average of around two-thirds capacity but with some plants operating at as low as 30%. Turkish firms were slightly better and had around 80% utilisation rate, but this was about to drastically change as the Turkish economy dipped into recession towards the end of 1994. Brazilian, Mexican and Turkish firms believed that with higher utilisation rates they could further reduce their unit costs.

In sum, plant and firm optimal scales seem to be increasing. Even in firms where unit costs have increased there seems to be some room for reducing unit costs if capacity utilisation is increased. New technologies, therefore, do not seem to be leading to 'descaling' but to 'scaling-up'.

4. Factors underlying increases in plant and firm scale.

i. Technical factors.

One of the key factors explaining changes in scope an scale has been the reduction of setting up times. To illustrate, take the case of a gearbox casing manufactured by a medium size company.

With conventional technologies the machining of gearbox casings required two vertical milling operations, two boring operations, three multi-spindle drilling and tapping drilling operations, one radial drill operation, one deburring operation and a final wash. Each of these operations was carried out in separate machines or required re-setting and replacing tools in any machine that had been used for a different operation. Not all operations were necessarily sequential although some were.

In this machining process, setting-up times consisted of machine adjusting, tool changing, loading and unloading workpiece, fixing workpiece to the machine tool, measuring the workpiece and test cutting. As in most cases these procedures were done manually, there was a set-up time on each occasion the same machining operation was carried out, but the set-up time was progressively reduced the larger the number of equal operations performed because of repetition.

The cumulative setting-up time in the machining process of gearbox casings amounted to around 3500 minutes for a batch size of 170-180, which represents 9% of machining time. This percentage was not substantially lower when batches of 1000 gearbox casings were produced before as a significant part of the setting up included loading and unloading which had to be done with any product.

With the new CNC machining centres, the setting up time for the same number of gearbox casings have been reduced to 3 hours or 2% of machining time, as they can mill, drill, tap and deburr without moving the workpiece from the machine bed. There is still the need to machine on two faces of the workpiece as one side is always clamped to the fixture so the workpiece has to be turned round for machining. Thus, the same piece is obtained after two machining operations and washing. Setting-up times in this case arise from fixing the tools in the machining centre, instructing the machine to perform required operations, and some electronic measuring of castings. Loading and unloading workpieces to fixtures and pallets can now be done off-line but as it still takes considerable time, it needs to be matched with machining times to ensure a steady flow of workpieces. Machining centres with an automatic tool changer allowing tool loading while machining other workpieces, can lead to further reductions in setting-up times.

Forty-two firms in our sample reported that setting-up times had fallen significantly from several hours to a few minutes. Only two Turkish mould producing firms reported increases of setting-up times because tolerances are said to be very small difficultying programming, which in any case has to be constantly modified while cutting. Tools are specific to each mould as well. There are several trial runs until engineers and machinists are satisfied that the correct measurements have been achieved and being each piece unique all this has to be done each time a new mould is manufactured. In Indian firms reductions in setting-up times tended to be lower than elsewhere because none of the machines in the sample had automatic pallet changer. Lower setting ups had the twin effect of reducing the initial fixed costs of a new batch and of permiting machines to be actually more time cutting metal, thus increasing output.

The second technical factor was the increase in machining speeds. In the case of gearbox casings, two types were machined before, one requiring 180 minutes accumulated machining or cycle time, the other needing 240 minutes. With the new technologies total machining time is 52 and 72 minutes for each type of gearbox casing respectively. All 36 firms in our sample said that machining speeds had increased. A Turkish firm furnished figures on machining times for 22 diferent standard parts. Savings in machining time averaged 68% for these parts, ranging from 46% to 86%. For the sample as a whole savings in machining time ranged from 15% to 9 times.

Another factor enabling higher scales is production management and engineering. Take the case of gearbox casings manufacturing. We have already pointed out the complex and 'nightmarish' conditions in which planning, scheduling and manufacturing actually took place and the disorganisation and ineffficiencies that ensued. In the case of gearbox casings machine utilisation ratios reached 60% on average --including time lost in setting-up--, operators spent considerable time away from their machines doing nothing, the factory was full of unfinished products, materials were wasted and no one knew where to find the right tools, all of which was reflected in having lead times for gearbox casings of 13 weeks, and even higher for the completely assembled gearbox.

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. Machine utilisation ratios increased in fourteen of our sample firms by between 7% to 98%. In four Indian firms machine availability had increased from an average 75% to 88%. There are still the need to solve the old problems of scheduling, routing and machine use, and new ones like tool management, as tools are becoming a significant part of cost, but the complexity of this task has been reduced. Improvements are 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 with labour spending more of their time on the machine. As a result reported lead times fell significantly. All Mexican and Venezuelan firms reported reductions in lead times to an average of one-quarter of what they were before.[12]

Labour management also became simpler because there were less workers and one worker could oversee more than one machine. Thus, it was possible, and even necessary because of the high capital costs as we will see, to increase the number of working shifts. On average working shifts increased from around 1.5 per day with old technologies to 2.5 per day with new ones.

All in all, lower setting up times made possible the reduction in batch sizes and larger variety but at the same time it led to higher machine productivity. This together with the fact that machines were much faster than the conventional technologies predominantly in use, that organising the factory became simpler and that shifts increased resulted in significant gains in terms of output or productive capacity.

ii. Economic factors.

Table 14 shows the changes in unit cost structure for a number of firms in our sample. Several conclusions meet immediately the eye. First, as expected, capital costs became a significant unit cost factor. For one Mexican firm the adoption of new technologies implied a three-fold increase in

[12] A Mexican firm stated that lead time reductions also depended on reductions in administrative lead times. It could reduce its production lead time from a month to a day but getting the paper work ready for the sale still took a week. As a result the firm was studying undertaking a major administrative reform prior to undertaking additional investment in CNC machine tools.

investment because of the costs of the new equipment. Higher capital costs had been reflected in significant increase in depreciation costs. Oil-hydro, a Brazilian manufacturer of oil valves declared and average annual investment in CNC machine tools since acquisitions started of US$ 1.1mn which was higher than any previous record of capital investment. Even though prices of CNC machine tools have fallen drastically in Brazil they are nevertheless still more expensive than conventional machines. Nine Indian firms reported increases in capital expenditure of between since adoption of 10% to 250%.

Many firms saved on building space as the new, fewer machines require less area, but as plants had been built for the previous number of machines the result had been more empty space available for future expansion. It also allows firms to keep old machines for emergencies much longer than if a newer, smaller plant would have been built. On the whole, capital fixed costs are the single most important economic factor underlying increases in optimal scale.

Labour costs fell significantly with the exception of firms in Turkey which were facing major government determined real wage increases. There were also significant reductions in employment in many of the firms further reducing labour cost share in the total. All firms which addresed the issue said that training costs were increasing in order to adapt the skill of workers to the new technologies and organisational concepts. The new technologies increased labour productivity bt between 50% and 330% in Turkey and between 16% and 300% in Mexico.

Raw materials unit costs have also fallen substantially in around three-quartes of the firms that provided data. A major factor in this case has been the better utilisation of castings. In some cases waste --mainly swarf and metal offcuts-- has been reduced in Venezuela by between 60% and 90% and by 40% in Mexico because of more precise machining and by using offcuts for other parts. Several Mexican firms had less than 1% scrap rates per year. Final product rejection rates fell in India to around one-third of what they were with conventional technologies and in Venezuela they also fell by between 63% and 98%. The reduction of scrap rates has been a significant factor explaining higher output because of less waste.

Inventories of raw materials, work in progress and finished goods were also reduced gradually over the years. In Venezuela inventories of raw materials fell by an average of 65% and in India by 50%.

Other unit costs which include mainly the costs of energy rose in a significant number of enterprises, notably in Venezuela and Turkey. Despite the much lower energy requirement of the AC and DC motors driving the spindles of lathes and machining centres the share of this factor rose in eleven firms. This was the result of price liberalisation and privatisation of public services in those countries which had resulted in huge jumps in the prices of utilities.

Overhead unit costs have increased in ten firms mainly due to higher marketing and administration costs. By the mid-eighties there was no proper accounting system in many firms in our sample. With the increasing information and sales being handled some firms felt the need to renovate their administration and accounting procedures. Marketing unit costs have also increased partly due to the hiring of new engineers to handle some of the new large customers who need a specialised approach. Research and development unit costs have not changed significantly as most firms are prefering an imitation strategy to product develpment.

VI. CONCLUSIONS

As has already been pointed out in Alcorta (1994) the 'de-scaling' argument is based on a number of confusions and misconceptions. It confuses product with plant scale, greater divisibility of capital and reductions in employment and physical size of plants with reductions in optimal scale, product differentiation and decentralisation with 'de-scaling', rigid inflexible technologies with conventional machine tools, falling semiconductor prices with reductions in capital costs and, more generally, supply with demand factors. The evidence of developing countries clearly shows that product scale does not necessarily fall but rather adjusts to changes in demand. That while there is some increase in the supply of new products, mostly it has been a case of variations of existing products and of vertical integration to the manufacture of parts and components. And, that plant and firm optimal scales increase. Hence, new technologies result in 'scaling-up' not in 'de-scaling'.

What prospects for industrialisation in developing countries resulting from NT then? The first conclusion that emerges from this review is that the Schumacher small-scale decentralised industrialisation model that underlies the 'de-scaling' literature, will clearly not be the outcome of the diffusion of NT. For as many different models, varieties or sizes of any product, plants will still need to produce large volumes to be efficient. Or, if design capabilities are to be included, they would have to produce even more to pay for the fixed costs of research and development. Thus, developing countries that cannot provide these levels of 'aggregate' demand, either locally or from exports, will not be able to produce efficiently. As with 'old' technologies' there will still be an 'aggregate' scale barrier to entry which implies that only firms, with substantial investment capacity --and probably also guaranteed markets--, will be able to initiate manufacturing production in these countries.

Small firms have some advantages over large ones, they are younger and more dynamic, less vertically integrated, more flexible and can today deliver the same standard of quality as a large firm, but the data presented in this research suggested that to make use of those advantages close ties need to be developed with larger firms in order to obtain information and markets.

Second, even if there was 'de-scaling', the evidence showed that the adoption of NT is not an easy process and that there is considerably more 'learning by doing' and 'learning by using' than what the 'de-scaling' literature admits. And this seems to be also somewhat true for organisational techniques. Indeed, though NT are also helping in the learning process and are making production management and engineering simpler, designing new products and parts and modifying production processes still creates major disruptions within firms in terms of plant organisation and skill requirements that most of them are not able to handle.

As far as policy implications for developing countries are concerned, the significant gains in terms of quality, productivity, flexibility and lower production costs and the changes that are ocurring throughout engineering may leave them with little option but to adopt these new technologies if they want to remain in the market. Thus, policy should be oriented to the prompt diffusion of flexible automation, to develop the basic infrastructure for their effective use and to provide the training in the new skills that are emerging. State policy should also focus in smoothing the social disruptions and lose of employment that may arise out of the sustained diffusion of new technologies.

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