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The Impact of New Technologies on Scale in Manufacturing Industry:

Issues and Evidence

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CONTENTS

1. INTRODUCTION

Developments in the fields of microelectronic, information and organisation technologies have led to a host of innovations which seem to be radically changing the nature of manufacturing industry. The increasing replacement of mass production, specialised, single-purpose, fixed equipment by computer aided design and engineering capabilities (CAD/CAE), robots, automatic handling and transporting devices, flexible manufacturing systems (FMS), computer aided/integrated manufacturing (CAM/CIM), cellular manufacturing, just-in-time (JIT) techniques, materials resource planning (MRP) and telematics has allowed firms to produce a larger variety of outputs efficiently in smaller batches and less time.

The greater flexibility of new technologies (NT) is also believed to have important implications for the level of 'optimal' scales. Contrary to the previous 'mass production' technological paradigm where increasing scales were crucial to cost reductions, NT's flexibility is said to provide "opportunities to switch production between products and so reverse the tendency towards greater scale" (Kaplinsky, 1990a, pg. 154). A similar view is put forward by Acs et al (1990), who argue that flexible production means that the "optimal size of plant and firm declines and entry occurs by small-scale-flexible producers" (pg. 146). This 'de-scaling' view is 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' in manufacturing industry could have at least five important related consequences for smaller scale firms and industrialisation. First, it would increase the efficiency of small-scale production (Dosi, 1988). Second, it may decrease the importance of plant-related economies of scale that were the source of productivity growth before NT were introduced (Dosi, 1988). Third, insofar as scale is a barrier to entry to other firms (Bain, 1956), more entry and competition by smaller firms could be expected. Furthermore, it could reduce barriers to entry in international trade in some sectors and facilitate the establishment of national industries where it was previously not feasible. Fourth, it may ease the 'infant industry' process that has complicated industrialisation in many developing countries (United Nations University, 1987). Smaller scales may allow for 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. Finally, it is likely to reduce the importance of 'world factories' producing on a global scale and therefore change the pattern of location of industry (Kaplinsky, 1990a). It could pave the way to new patterns of decentralised industrialisation based on small production units located outside the large urban centres (United Nations University, 1987).

The potential impact of 'de-scaling' on plants, firms, industries, and countries clearly warrants careful examination of the issues involved. Accordingly, the main aim of this paper is to examine critically the literature on the relationship between NT and scale. It will address the question of whether and to what extent NT reduce the optimal scale of production units, a phenomenon we shall describe as 'de-scaling'. Insofar as optimal scale may take place at different dimensions: product (batch size), plant (total plant output), and firm (total firm production), and that each one could be affected differently by technology, the discussion will be done separately for each of these levels.

The main argument will be that, although NT may have a significant scale reduction effect at product level, it is not clear they would have a similar impact at plant level. Furthermore, the impact at firm level may be 'scaling-up' rather than 'de-scaling'. Although 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' and little research has been done on the topic, it seems that the trend, if any, will be towards larger firms and organisations rather than smaller ones. This statement, however, does not mean that smaller firms are doomed nor that opportunities are totally closed for them. Small firms will continue to emerge, as they have always done, catering for specialised markets or by selling service-linked products. NT will offer small firms the possibility to improve quality standards and to coordinate and share fixed costs.

The paper will proceed as follows. The next section will present a simple conceptual framework examining the relationship between technical change and unit 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 manufacturing industry. The following section will look into the question of whether NT are 'de-scaling'. It will do so by examining the arguments put forward by 'de-scaling' authors, as well as the empirical evidence supporting those views. It will focus on the relationship between costs and technological change in each dimension of scale. Inter-industry differences will try to be accounted for. In a fifth section, some other options that NT allegedly open for small firms will be discussed, namely the possibilities of producing in 'new' industries and of networking. The paper will end with some comments on the impact of NT on the potential for development of small-scale firms.

2. A SIMPLE CONCEPTUAL FRAMEWORK

2.1 Some Basic Definitions: Scale and Scope

Scale refers to size of output or capacity of production units; *economies of scale* refer to reductions in unit costs due to increases in size of output. Economies of scale are said to exist if total cost rises less proportionately than output, and optimal scale occurs at the point where any increase in output no longer reduces but raises unit costs.

According to Scherer et al (1975) and Scherer and Ross (1991), scale and economies of scale are better analysed in terms of three dimensions: product, plant or firm. *Product scale* alludes to the volume of any single product made. Product-scale economies may arise from unit cost reductions due to the division of labour and specialisation of workers and equipment. Longer production runs allow for the separation of tasks and for workers to do their individual jobs rapidly and precisely, while avoiding the loss of time and effort associated with moving from one task to another. They also allow for the use of more efficient, specific-purpose machinery and mechanised production processes. A second source is the learning potential of long production runs. Where intricate operations and complex process adjustment are involved, unit costs may fall if workers learn by doing. A third source is the indivisibility or lumpiness of capital equipment. Machines are normally only available in a limited number of capacities and their price tends to increase less than proportionately with rises in capacity.

Another important source of product-scale economies, and particularly relevant to our subsequent discussion, is the cost of changing and setting-up the equipment for performing a particular batch or product run (Carlsson, 1989a; Kaplinsky, 1991; Pratten, 1975, 1991; Scherer et al, 1975; Silberston, 1972). Batch or lot size is the number of equal items or products treated in a certain process or sequence of operations. It refers to the total life of each production run, which could last hours, weeks, months or even several years[1]. The larger the batch or lot size --or the longer the production run-- the lower the unit costs due to refitting each machine with the appropriate tools, resetting the equipment, and/or changing the whole production line over from the previous item to the new one, and, therefore, the greater the incentive to continue producing the same item or product, although it may also mean keeping a large inventory of inputs and final goods to deal with short-term variations in demand[2].

Within a given production capacity and technology, the setting-up or change-over costs and the nature of demand are the key factors in determining when or whether a new product is manufactured (Ayres, 1991; Morroni, 1991). The classical example is Ford's replacement of the model T car by the model A car, which required closing down the factory for nine months in 1926 (Abernathy, 1978)[3]. The car industry has always been under immense pressure not to change car model and hence why some models remain several years in the market. According to Carlsson (1989a), in many operations in the metalworking sector the 'typical' set-up time was 20-30% of processing time. In other industries, such as printing, the initial typesetting costs can be so high that they sometimes make the publication of specialised or academic books or journals economically unfeasible. Very few books print as many copies as the Bible or Porter's 'Competitive Advantage'.[4]

Plant scale, in turn, is normally associated to the total output of an entire plant in process or 'fluid-flow' industries, such as oil refining, chemicals, steel and cement, for a given period of time --normally one year. In addition to any relevant source of economies of scale already mentioned, plant-related economies may also emerge from the technical volume-surface relationship known as the '0.6 rule'. The cost of construction of any container increases in line with its surface area, whereas the capacity increases with volume. Since the area of a sphere or cylinder varies as the two-thirds power of volume, the cost of building some process-industry plants rises roughly as the two-thirds power of their capacity.[5] Another source of economies of scale at plant level arises from what is called the 'economies of massed reserves'. Larger plants can reduce the impact on unit costs of keeping reserve machines or spare parts for breakdowns or to replace those undergoing servicing. Cost savings can also arise from the fact that the number of staff required for maintenance and service increases much less than proportionately than output (Scherer and Ross, 1991; Pratten, 1975, 1991).

Although very little discussed in the traditional analysis of scale, plant scale also applies to discrete multi-product plants. Reality seems to be extensively populated by production facilities manufacturing many different products. Producers of garments, textiles, consumer electronics goods, home appliances, engines and machine tools, constantly have to switch models or manufacture according to varying technical specifications to satisfy differentiated demand. In these cases, plant scale alludes to the aggregate output of the plant.

Producing more than one good implies not only considering the setting-up, change-over and investment costs but also the potential cost effects of joint-production. Baumol et al (1988; see also Bailey and Friedlaender, 1982) have addressed this issue and have developed the concepts of scope and economies of scope which they consider a complement to the traditional concepts of scale and economies of scale.

Scope basically stands for product range; economies of scope arise when the cost of making goods jointly is less than making the same total quantity of the same goods separately.[6] Economies of scope arise from the sharing or joint utilisation of inputs. It occurs when a given factor or input is imperfectly divisible, so that the production of a specific product or number of them may lead to under-utilisation of that input. It also happens when using inputs that may have some properties of a public good, so that when purchased for one production process they may be freely available to another (Baumol et al, 1988; Bailey and Friedlaender, 1982).[7]

Turning to the firm dimension of scale --i.e. the total output of the firm-- economies of scale and economies of scope arise from both the 'fixed' and 'shared' nature of certain 'intangible' investments, such as research and development (R & D), marketing and management.

Budgets for the development of new products and processes are normally 'rule of thumb' amounts, reached on the basis of previous years' sales, levels of retained profits, the expenditure of potential competitors, minimum threshold considerations, the average allocation of the industry and the emerging technological opportunities (Freeman, 1982; Hay and Morris, 1991). Marketing and distribution expenditures are also set amounts resulting from similar factors. For advertising to be effective there are certain minimum threshold levels of messages that have to be transmitted. Consumer durables and office automation industries necessarily require specialised dealer networks and after sales service. Operating a sales force requires investment in training and specialised equipment (Scherer and Ross, 1991). Management costs are also pre-set and depend on a minimum number of functions and hierarchical levels --and therefore managers-- and of specialised equipment that are required for the normal operation of any firm (Koutsoyiannis, 1980). Scale gains arise, therefore, from the possibility of spreading all these 'fixed' costs among larger total volumes.

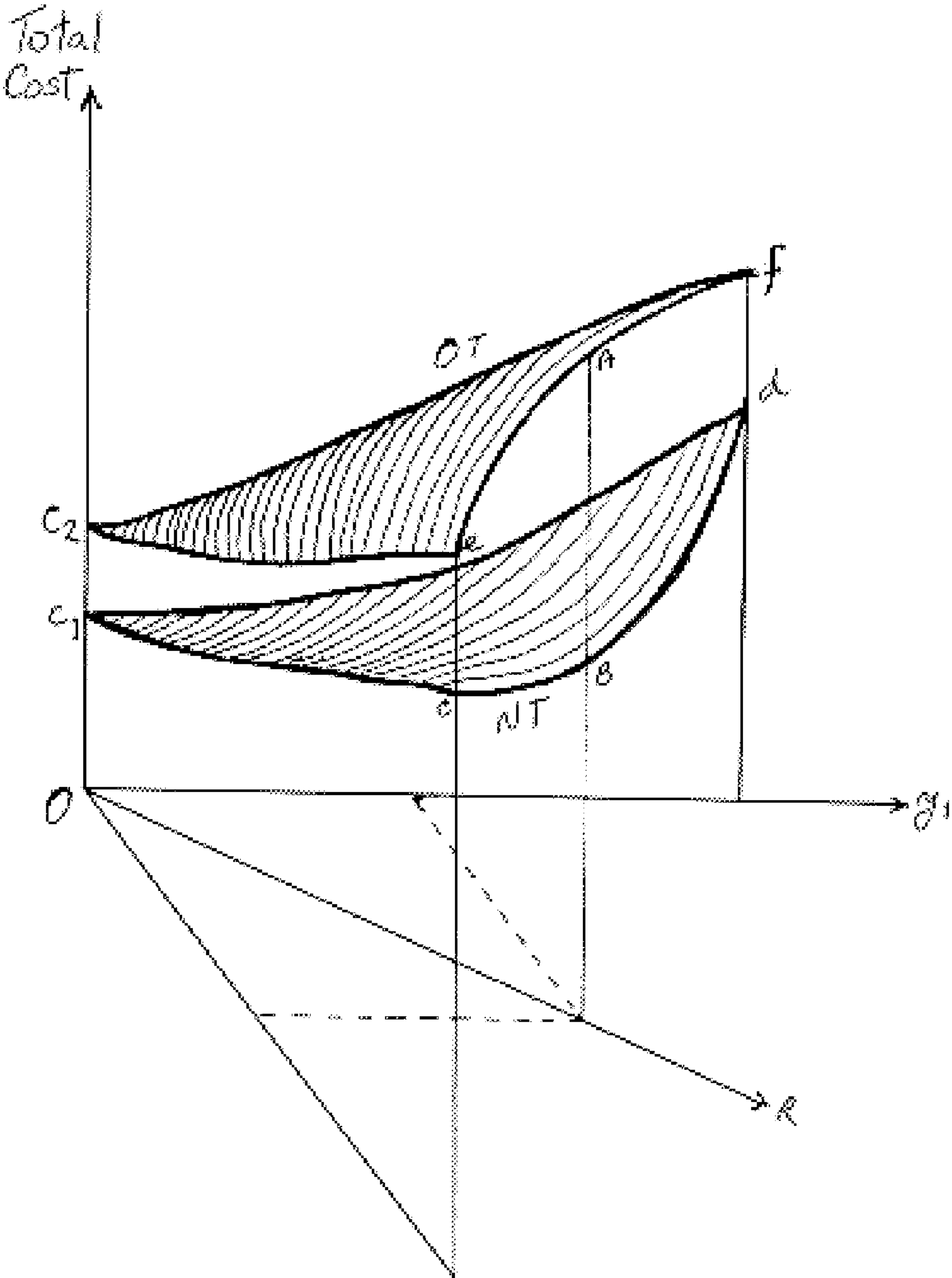
As far as economies of scope at firm level are concerned, they emanate from exchanging and pooling the information and knowhow available from several projects being undertaken simultaneously (Teece, 1980), and from using marketing, distribution and management facilities for more than a single product.

2.2 Technical Change, Costs, and Optimal Scale

Traditionally, the impact of technical change on production is normally discussed in terms of shifts in the production function. It may lead to more output being produced with the same resources or to the same output being produced with fewer resources. Technical change's impact on production 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 lower cost.

The existence of multi-product firms introduces the possibility of technical change also leading to lower levels of cost not only due to savings in factors and/or inputs costs 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 also point out that the development of technologies that allowed switching of tasks and varying the order in which parts are transferred is one of the main factors underlying the achievement of economies of scope.

Figure 1 shows the total cost surfaces of producing the same two goods, y_1 and y_2, prior to 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 is produced, then we have a conventional single-product cost curve on each horizontal axis. Cost surface $c_2$ef 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. Thus, there are 'diseconomies' of scope, as reflected by the shape of the cross section connecting points e and f --i.e. the costs of producing y_1 and y_2 separately is lower than producing them jointly.[8]


Total Cost
f
OT
A
d
C2
e
C1
B
c
NT
O
y1
R
y2

Following the introduction of a 'new' cost saving technology, a new, lower cost surface $c_1$cd emerges. Total costs have fallen due to a reduction of factors and/or inputs 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.[9]

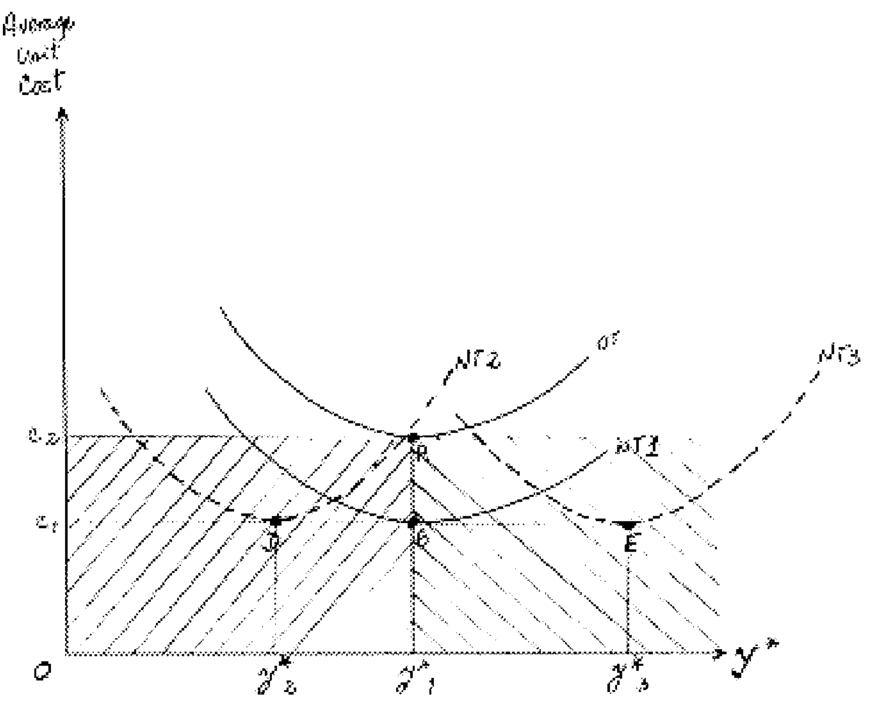
The discussion thus far does not consider the impact of technical change on scale. Stevenson (1980), and more recently Stiglitz (1987) and Markowski and Jubb (1989), raised the possibility that technical change may also have a scale 'bias'. In Stevenson's (1980) view: "Such a bias would alter the range 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), in turn, have extended this discussion to the multi-product setting and have explored some of the emerging scale and cost relationships.

To exemplify how technical change may affect scale, let's 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.[10]

Figure 2 shows the average unit cost curves 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 for 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 were 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.

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, such as capital and labour, 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. Cost and technical factors together will determine if a 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.

Figure 2.



Two final points arise in connection with the relationship between technological change, costs and scale. The first refers to the relevance of our previous discussion to the dimensions of scale. Insofar as the cost axis includes change-over costs, production costs, intangible investments, 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 all dimensions of scale. The second regards the apparent nature of today's technological change. It is quite possible, and this will be the topic of the following section, that technological change will not only lead to the replacement of production facilities producing one or two goods by another producing the same number of goods. New production facilities may be capable of producing a much larger variety of goods. Thus, in reality, there could be much more complex interactions and trade-offs between costs, scale and technology.

3. THE IMPACT OF NEW TECHNOLOGIES ON MANUFACTURING INDUSTRY

The 'Modern Technology' Literature View[11]

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 new tools and equipment or 'advanced manufacturing equipment' (AME).[12]

The new AME have a number of properties or characteristics that are said to underlie their impact on the manufacturing process. These include small physical size, reliability, adaptability, modularity, divisibility, speed of operation and low energy consumption. Small physical size allows considerable space-savings and ease of access in factories, as well as a greater number of options in production layouts (Bessant et al, 1981). It also permits the processing and storage of large amounts of information (Markowski and Jubb, 1989). The lack of moving parts and low operating demands make microprocessors extremely reliable. Maintenance is eased by built-in diagnostics and indicators which identify the source of failure (Bessant et al, 1981). Microprocessors do not act in a fixed way to an input signal, but can be programmed in different ways and therefore vary in their response accordingly (Braun, 1980). The design and manufacture of new products and equipment can be built from a range of independent modules, programs, units, or parts which, together, form an expandable system (Hobday, 1990a). The manufacture of AME requires a smaller degree of electromechanical interfacing and engineering, as the main operating functions are built into the system's logic. Semiconductors constitute the 'building blocks' of final products and pieces of equipment and are increasingly taking on the functional tasks of them, therefore making it easier to build similar products of different sizes. Some standardised devices can be purchased directly from semiconductor manufacturers and mounted onto own printed circuit boards and equipment (Hobday, 1990a). Contrary to mechanical and electromechanical equipment, microlectronic systems eliminate inertial effects, allowing for faster acceleration and higher precision. Also, though they may fail, they rarely suffer from wear, thus increasing the accuracy of the operations performed (Twiss, 1981). Finally, microprocessors consume very little energy and can operate for very long periods with a small power source (Twiss, 1981).

It is asserted that, together with these 'hardware' technologies, a number of new organisational changes have also emerged (Best, 1990; Kaplinsky, 1984, 1991; Womack et al, 1990).[13] These organisational innovations are essentially aimed at improving the flow of information and communication and enhancing the decision, coordinating and cooperating capacity of managers and workers within and between firms. They are also directed at being more responsive to changes in demand and strengthening the quality of the goods produced.[14]

Most authors within this framework point out that the full benefits of the new technological and organisational innovations can only be fully reaped when they are introduced in combination. For Milgrom and Roberts (1990), 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 is introduced (Milgrom and Roberts, 1990). There are also complementarities in inter-firm relations, making coordination not only within enterprises but also between them a key aspect of modern technology. Kaplinsky (1984), Hoffman and Kaplinsky (1988) and Perez (1985) take this view further and argue that the introduction of the full range of NT in all activities of the firm and its relationships with suppliers and consumers produces 'synergies', i.e. the total gains are more than the sum of the individual gains.

The application of NT to manufacturing industry is, in the view of the 'modern technology' literature, changing its nature in several respects (Bessant, 1991; Ferraz et al, 1991; Kaplinsky, 1984, 1990a, 1991; Piore and Sable, 1984; Perez, 1989). In contrast with the old 'mass production technological paradigm', the introduction of NT leads to qualitatively different command and control structures, work organisation patterns and competitive strategies.[15] Bureaucratic and centralised lines of command and communications are replaced by flatter hierarchies and informal control mechanisms based on goal setting and participatory decision-making. Separate functional departments, standard routines and procedures, and individual job definitions are also displaced by interactive and cooperative links and adaptable procedures between departments, groups and individuals. Labour is no longer seen as a cost or as doing a single specialised function, but as human capital, and therefore there is much more emphasis on having a multi-skilled, creative, knowledgeable, trustworthy and responsible work force. Finally, arm's length relationships with suppliers and competitors are displaced by collaborative links with suppliers, customers and sometimes with competitors. Competition is no longer based on cost cutting but on continuous innovation and fast market response.

One of the most important aspects of the NT is the 'flexibility' they have introduced into the production process. Production flexibility is defined by this literature in terms of the capacity to switch rapidly to the production of different products (Carlsson, 1989a; Morroni, 1991). Production facilities can now produce a far wider range or scope of products than before. Flexibility has an 'operational' element which is related to the capacity to adjust easily output proportions for a given range of individual goods. It also has a 'strategic' element which refers to the capacity to alter the product mix by introducing new products or modifying the quality of existing ones.[16]

Greater production flexibility or scope is reflected in the increase in product variety witnessed in recent years. Carlsson (1989b) points out that the average supermarket store in the United States stocks roughly twice as many items as it did ten years ago. According to Belussi (1987, 1992), after the introduction of CAD in Benetton, the Italian fashion designer, the number of models rose from a few to 1,200. Womack et al's (1990) study shows that, in the car industry, the number of products, models, and variations within them has increased substantially due to the introduction of NT. In 1955 the average worldwide sales volume of a particular model of vehicle amounted to 259,000 units, while in 1989 the equivalent figure was 112,000 (Womack et al, 1990). Between 1982 and 1990, Japanese firms, the main users of NT, increased their product portfolio from forty-seven to eighty-four models (Womack et al, 1990). The German car producer Audi manufactures a completely different model every 20,000 cars (Ayres, 1991). Kaplinsky's (1991) study on Lucas LFS, the British car component manufacturer, finds that, following the restructuring of the company and the introduction of new flexible technologies, there was a reduction in the share of the two dominant product varieties from 90% to just over 50% of total output. Bessant (1991) reports that a typical TV and video-recorder manufacturer offers on average between 30-40 models of each product, with some offering as many as 70 different models. He also points out that only between 1981 and 1984, the life cycle of Japanese general, electric, transport, and precision machinery fell by around 25%. In the semiconductor industry, major new products are now introduced every 3 years, while in the early 1980s the average was 5-7 years (Ayres, 1991).[17]

4. ARE NEW TECHNOLOGIES 'DE-SCALING'?

The capacity to produce flexibly is also said to have profound implications for optimal scale. One passionate, populist and popular, but rather absurd and unfounded view, is that NT will finally make Schumacher's 'small is beautiful' dream a reality:

> "Rather than pushing decisions up through the hierarchy, microelectronics pulls them remorselessly down to the individual. This is the law of the microcosm. This is the secret of the new American challenge in the global economy. The new law of the microcosm has emerged, leaving Orwell, von Neumann, and even Charles Ferguson in its wake. With the microprocessor and related chip technologies, the computing industry has replaced its previous economies of scale with the new economies of microscale." (Gilder, 1988, pg 57).

A second, more serious approach, put forward by authors like Acs and Audretsch (1989, 1990a, 1990b), Acs et al (1990), Carlsson (1989b), Dosi (1988), Kaplinsky (1984, 1990a, 1991) and Perez (1985), argues that, although the application of NT will result in an overall trend towards optimal scale reduction, 'de-scaling' will not necessarily affect equally every dimension of scale .

4.1 The Product Dimension of Scale

At product level the argument is basically that, unlike 'old' specialised machines, the new flexible equipment can be easily and rapidly switched to different configurations or standards. The speed of variation can be further accelerated if there is an 'automatic' --'real time' planning-- relationship and feedback between design, logistics, manufacture and marketing so that the whole production and distribution process is coordinated and 'optimised' and therefore little time and resources are wasted in waiting, storage and transport. Three important results follow (Bolwijn et al, 1986; Kaplinsky, 1990; Perez, 1985). First, there are savings in inventories as there is no longer the need of keeping large stocks of inputs, work in progress or final goods in the factory, or even in the shops. Second, there are reductions in waste and improvements in quality, also partly due to the better trained and 'quality-oriented' work force. Third, the time required to switch the production from one good to the other is drastically reduced. There is, therefore, a significant reduction in setting up and change-over costs which in turn allows the production of smaller 'optimal' batch sizes or shorter production runs, as there is no longer the need to produce as many equal products as before to 'dilute' these costs.

There seems to be some evidence to back the set-up time reduction claim, although not as much as some of the authors within this literature would claim. Research by Carlsson (1989a) on the metalworking industry shows that, for processes comparable with Sweden, some factories in Japan have reduced set-up times from 1-1.5 hours to only a few minutes by using an electronic pallet system which allows a new tool to be brought up to the machine prior to change-over, with an empty pallet being ready to receive the used tool, and, as a result, minimising machine downtime. Another study by Hoffman and Kaplinsky (1988) shows that set-up times in forging and casting in Toyota's stamping division fell between 1970 and 1980 from 100-200 minutes to 10 minutes and from 60 minutes to 4 minutes. Average lot sizes also fell during the same period from 5,000 to 500. Kaplinsky's (1991) already mentioned study on Lucas LFS points to a drop in lead times --the period between placing an order and the delivery of the product-- due to a change in technology. Production planning, manufacturing and storage time, which include set-up times in manufacturing, fell from 8, 11 and 2 weeks to 2.2, 1.2 and 0.8 weeks respectively. Womack et al's (1990) study of the car industry shows that, for Japanese 'lean' producers, the engineering change-over costs as share of total die costs averages between 10-20%. In the case of American and European producers the equivalent figures are 30-50% and 10-30% of an even higher total. Besides, Japanese producers take only one month from the start of production to the sale of the vehicle, while American and European companies take between 2-4 months.

There is some evidence in other industries too. In clothing, a detailed industry-wide study by Hoffman and Rush (1988), also summarised in United Nations Industrial Development Organization (UNIDO, 1989), found that, after the introduction of CAD/CAM, the industry has reduced the period of the design, grading materials and cutting of a new product from two to three weeks to only 48 hours. In Bennetton, the introduction of a CAD system for size grading has reduced the operation from 24 hours to 15 minutes and has increased the rate of utilisation of fabrics from 75-76% to 85-89% (Belussi, 1987, 1992). Carlsson (1989a) also illustrates how in the printing industry the set-up times in a mechanical press have been reduced drastically, from 45 minutes to 10 minutes, through an investment in a pre-set device that cost one-tenth of the saving in reduced setup times during the first year of application. More generally, the introduction of desk-top publishing is making the printing industry look more like a 'fluid flow' industry with the concurrent reduction in setting-up times and batch sizes. In 1971 printing an individual title required 10,000 hardback and 100,000 paperback copies (Pratten, 1988) whereas today the average run is around 1,000 copies which is less than what was produced in the smallest firm with traditional equipment.

A thorough study on costs in the bicycle industry based on simulations under different technological alternatives, by Mody et al (1991d), also provides some evidence in the same direction. The simulations show that, after introducing organisational improvements and flexible hardware technologies, a 'typical' firm in the industry would not only see the costs of adding a new product variety increase much less than with 'old' fixed automation, but also face an overall unit cost reduction for each bicycle model. The figures show that the unit costs of producing around 70 varieties of bicycles with NT would be slightly lower than the unit costs of producing 5 varieties with old technologies, although this implied also an increase in the total output of the factory.

While more research into other industries is required before a firm conclusion can be reached, existing evidence points in the direction of a reduction of setting up times and change-over costs, and thus a reduction in product scale. In fact, we have not come across a single case where increases in setting up times have been reported. Nevertheless, there is one additional point worth stressing. It refers to the degree of homogeneity or heterogeneity of the new products. Are differences between products substantial? Or, is it the case that minor differences or 'cosmetic changes' are now being considered as 'new' products? Put in other terms, how flexible is flexible? In his study into Lucas LFS, Kaplinsky (1991) found that, after reorganisation, the plant was producing the same three products as before. In the case of one good, the number of varieties increased from seven to nine, in the second product from two to eight, while in the third product there were no varieties either before or after. The major change was that there were different mixes of batch sizes, so the factory depended much less on two particular varieties, which used to account for a very large proportion of total sales. Ayres (1991) points out that there continues to be a trade-off between product complexity in terms of shapes, number of parts and difficulty to assemble, and flexibility. In other words, the extent of the reduction in set-up times is still highly sensitive to the depth of the changes in the product. Until robots with visual optics capacity and perfectly switchable equipment come into stream, which may be a long way away and may never be achieved, it will still be very difficult --or too expensive-- constantly to introduce substantial modifications on the characteristics of certain goods.

The above discussion leads to two final remarks on the degree of flexibility. First, there was not that little variety under 'mass' production. Producers did introduce a degree of product differentiation and variety. They did so by adding production lines, introducing process modifications that allowed a degree of product differentiation, and through subcontracting. Second, there is not that much variety under NT either. New products have emerged, many of which are radically different from earlier ones. Products are also now available in more models, varieties within them, different sizes and with varying technical specifications, which, given a strict definition of homogeneity, would have to be considered as different goods. However, the degree of flexibility is not as high as some may imply, as many of the alleged 'new' products are merely the result of minor modifications or varieties of 'old' ones. It is certainly not the case, as Womack et al (1990) point out, that: "the world awaited the arrival of lean production for a true renaissance in consumer choice. And the end is not yet in sight." (pg. 126). In sum, portraying 'mass production' as the period of everyone driving a 'black Ford Model T', and today's flexibility as providing custom-built products for everyone, is a gross misrepresentation of the real capabilities of 'old' and 'new' technologies.

4.2 The Plant Dimension of Scale

Will NT reduce plant scales? Carlsson (1989b) argues that the product flexibility of NT is increasingly making it more difficult to keep highly dedicated equipment operating at full capacity. Higher levels of personal income have led to an increasing demand for variety that has resulted in chronic capacity under-utilisation in specialised plants. Given that specialised equipment's profitability is very sensitive not only to changeover costs but also to capacity utilisation, new plants will increasingly have to be built to accommodate an even more changing demand. Carlsson adds that the type of plant organisation, labour skills and space requirements to make maximum use of available NT will necessarily lead to the establishment of smaller production facilities:

> "The result is that restructuring of this sort is likely to lead to the establishment of new plants with more flexibility and lower total employment, at the same time as employment is reduced in older facilities. Thus this mechanism can help to explain both the increase in the number of plants and the decline in average plant size." (Carlsson, 1989b, pg. 35).

Carlsson (1989b) and Acs and Audretsch (1990a) produce some statistical evidence to support this claim. Using employment-based indicators of size, they show that in metalworking industries in countries such as the US, UK, West Germany, Italy and Japan, the proportion of small firms in the total increases while at the same time the average size of firms in these industries decreases. As these industries have increasingly used NCMT and robotics, they conclude that there is indeed a 'de-scaling' impact of NT.

There are two main problems with the evidence presented by these authors, some of which they acknowledge but unfortunately do not give the corresponding importance. The first refers to the employment indicator used as the measure for 'de-scaling'. It is well known that the introduction of labour saving techniques and their ensuing increase in productivity could result in smaller plants in terms of employment but not necessarily in terms of optimal output. Employment based indicators are therefore poor indicators of 'de-scaling' as far as plant size is concerned.[18] Second, even if the employment-based indicator was a good proxy for optimal scale, the evidence does not necessarily show 'de-scaling' in terms of plant size reduction as a result of NT. It is not possible to tell from average or aggregate figures whether old large plants have been replaced or that they coexist with new smaller plants that have been built for specialised markets. Even if there is a degree of capacity reduction, vertical disintegration or firm fragmentation leading to smaller sizes, it does not follow that it is the result of the introduction of NT, as it may well be the result of firms responding to a fall in demand or to other institutional influences. Only through a case-by-case approach can 'de-scaling' be properly assessed.

Plant 'de-scaling' authors assume a relatively higher, and growing, demand for differentiated goods vis-a-vis standardised ones. Williams et al (1987) contest this view on grounds that in the case of some consumer goods, like colour TVs, households may prefer to buy two or more similar products than to search for more sophisticated models. Williams et al (1987) add that there is also a significant replacement market for the more 'traditional' goods. Furthermore, it is not guaranteed that the past trend of rising real incomes in developed countries, that may have underpinned the demand for differentiated goods, will continue, with the attendant effect on the consumption of 'new' or 'distinct' products. More importantly, there is an implicit view in the literature that most consumers in developed countries are of the 'high-income' type, i.e. they only demand better quality, differentiated, and luxurious products as opposed to standardised and cheap goods, demanded by low-income groups (Stewart and James, 1982). This seems highly counter-intuitive, as one would expect to find even in the wealthiest country, a combination of high, medium and low income groups, with the latter two groups still demanding standardised goods. Moreover, Sayer (1988) adds that there is no reason to believe that high-income consumers will only demand new and different products. They may sometimes prefer low price or cheap replaceable goods. Besides, plant 'de-scaling' authors assume away the potential demand for cheaper standardised products existing in developing countries.

Carlsson also supposes that, in accommodating for a much more differentiated demand, firms will necessarily reduce total plant capacity and output in order to maximise capacity utilisation. If a firm were to continue using 'old' technologies this assumption would seem correct. However, precisely because of NT's flexibility, plants are more likely to increase the range of products offered to maximise capacity utilisation, achieve economies of scope and reduce unit costs. Furthermore, if competition is increasingly dependent on product variety, then there is additional pressure to be even more flexible. It may well be the case that flexibility has a positive --rather than negative-- association with scale, resulting in a 'scaling-up' effect in plants producing several goods. A highly flexible equipment such as FMS may require very large scales to be efficient.

There is increasing evidence that NT are having at least a neutral, if not positive, impact on the optimal level of output. According to Altshuler et al (1984), Bureau of Industry Economics (1988a), Jones and Womack (1985), Hoffman and Kaplinsky (1988), Lucke (1987), Pratten (1971, 1988) and Womack et al (1990), optimal output in the car industry had already stabilised at around 250,000 in the early 1970s. Since then the industry has gone through a number of modifications involving the introduction of NT, such as computer controlled machine tools, CAD/CAM, robots, Just-In-Time inventory management and total quality control techniques. New 'state of the art' plants being built today in United States and Europe have an average capacity of around 250,000-300,000 cars (Bureau of Industry Economics, 1988a; Womack et al, 1990). Thus the following conclusion by Altshuler et al (1984) on the impact of NT on flexibility and scale in the car industry seems very relevant:

> "New production hardware is already lowering the minimum efficient annual manufacturing scale for individual product lines in the auto industry and will lower it further in the future. For example, final-assembly plants were formerly most efficient when producing one model on a two-shift work schedule at a total volume of about 240,000 units per year. In the future, however, the increasing use of flexible automation able to assemble a wide range of products on the same line will mean that a plant may be highly efficient if the cumulative volume spread over several models is around 240,000." (pg. 182).

A detailed study by Edquist and Jacobsson (1988) on the car component industry finds a 'scaling-up' rather than 'de-scaling' effect. According to these authors, the complete crankshaft factory of Volvo Components in Sweden was recently retooled with NT equipment, including CNC lathes, robots, AGV and a central computer. The introduction of this technology reduced the total number of machines from 54 to 41 but cost 17% more than if old technology equipment had been used. The machines did reduce labour substantially, with only 40 workers being needed in three shifts as opposed to 90 workers in two shifts under old technologies. In addition, production capacity increased by 33% in comparison with the old machines. The higher utilisation ratio and the higher level of output of the new factory, meant that NT saved both capital and labour.

There are also scale increases in the bicycle industry. Around 100,000 units were required to be efficient in the early 1970s (Pratten, 1988). Today, Mody et al's (1991d) study mentioned earlier points out at a minimum efficient scale of around 250,000 units a year. They conclude that:

> "Automation increases the efficent size of the plant, but only to a small extent. It is often conjectured that the modern automated equipment is also modular, resulting in an actual decline in the efficient size of the plant. There is no support from our simulations for such a conjecture. What modern automated equipment does allow is the production of small lot sizes because the time to change machine settings for a different product becomes smaller with such equipment. However, to use the equipment efficiently, the annual throughput rate of the plant must increase, if only marginally." (pg 41).

In the semiconductor industry the scale changes would seem to be more drastic. Although there is no direct evidence on plant size, some idea can be obtained from the changes in capital requirements. For Ferguson (1988), Langlois et al (1988), Pozdena (1987) and United Nations Centre on Transnational Corporations (1988), the industry was initially based on small scale, labour intensive, highly innovative firms. However, since the late 1970s the industry had undergone a process of technical change which included the introduction of widespread microelectronics-based automation into the manufacturing process, as well as product modifications increasing the capacity of semiconductors

(Bolwijn et al, 1986; Mody and Wheeler, 1990). As a result, by the mid-1980s around 50% of total output was accounted for by the top ten producing firms in very few plants across the world.[19] An OECD (1985) study points out that the capital requirement to enter the semiconductor industry was US $ 0.1mn in 1954, US$ 0.5mn in 1967, US$ 5mn in 1976 and US$ 60mn in 1982. Langlois et al (1988) add that figures available for the mid-1980s estimate cost of entry into the 64K DRAM production at US$ 30-100mn and into the 256 DRAM production at around US$ 160mn. Ernst and O'Connor (1992) show that to start a minimum efficient size production facility today costs around US$ 1bn. Long-term scale trends in the semiconductor industry led the Organization for Economic Cooperation and Development (OECD, 1985) report to conclude that: "Whereas, in the early stages of growth of the industry, scale was not an important consideration, now it is considered an important barrier of entry" (pg. 39).

Small batch industries are no exception either. According to Watanabe (1987), where small batch production precluded firms from automation, microelectronic machinery, for instance robots, offers an opportunity for it because of their capacity to handle relatively more complex shapes. A study by Jacobsson (1989) on the production of numerically controlled machine tools shows that, from being a small to medium batch industry when based on metallurgy and mechanics, the industry, based today on electronics, requires very high volumes to remain in business. While before producers of numerically controlled lathes required around 100 units during any one year, today's producers require approximately 2,000 units per year to be efficient. Jacobsson adds that the unit cost differences between 'large-scale' and 'small-scale' modern producers is approximately 40 per cent. A survey of small scale firms in the electronic goods and instruments industries in the UK, by Pratten (1991), also shows that the new technology machine tools being used by these firms have a far greater capacity than the machines they replace. As a result, these firms have been forced to produce more and in larger variety to compete and survive. Perez (1985) and Hoffman and Rush (1988) also point at similar 'scaling-up' effects in the printing, mechanical engineering, clothing and furniture industries.

'Scaling-up' is also taking place in process or fluid-flow industries. Interestingly enough, it is in the 'small-scale' steel mini-mill sector, mentioned for a long-time as the paradigm of 'de-scaling', where this is occurring.[20] During the 1980s, the sector underwent a period of intense, industry-specific and microelectronics-based, technical change, which included the introduction of more efficient melting techniques, ladle furnaces, continuous casters, computers and electronic control equipment. As a result, the sector has been capable of reducing substantially material, energy, capital and labour costs, while at the same time improving significantly the quality of its output. Also, it is now capable of producing some tubular products and may, eventually, manufacture flat-rolled sheets. However, this has meant that the minimum economic scale of production for 'mini-mills' has risen too. In the 1990s it is expected that competitive mini-mills will have an annual capacity ranging from 500,000 to 1 mn tons, with the larger mills producing up to 2 mn tons annually (Mody et al., 1991c).

Another process industry that is facing 'scaling-up' is paper and pulp. Research carried out by the Bureau of Industry Economics (1988b) on the impact of microelectronics on scale in the industry also reached this conclusion. The industry has been introducing in recent years a number of minor process innovations, particularly in the area of chemical pulping, as well as several microelectronics-based process control equipment, like instrument panels and computerised process monitoring. Despite not being a typical area for CAD applications, this technology is also being used for new product development. Although the authors do not furnish specific figures, they describe the main effects of the introduction of NT as: the reduction in the share of labour in total costs due to falls in clerical employment; the integration of the control of previously separate parts of the production process and as a result an increase in the total processing speed; the reduction of setting-up and change-over times and as a result an increase in the range of output, particularly in paper making; and, finally, the overall reduction in waste of materials. As to plant scale, they note that "... in all pulp and paper making process the scale of facilities continues to increase over time as the diffusion of microelectronics progresses." (pg. 41).[21]

On the whole, available evidence strongly suggests that the introduction of NT is not leading to 'de-scaling' but rather to 'scaling-up'.[22] NT are also making it possible for even larger plants to become increasingly more flexible. This seems to be occurring in discrete and process industries and in small and large batch size industries. The paradox of this outcome is that it makes flexibility, a characteristic formerly only associated to small scale production, available also to large scale producers. Hence, with the spread of NT, larger firms can acquire one of the key strengths of smaller ones.

Underlying this 'scaling-up' effect there is a complex interaction between costs and technological factors that seems worth exploring briefly. Most studies on the impact of NT show substantial savings in labour and input costs which arise both from cutbacks in production costs of individual goods and from reductions in costs due to joint production. For a given level of output, labour costs clearly decline. There are significant reductions in employment in the production, material handling, maintenance, quality control and plant related clerical areas as the new machines and computers take-over many of the functions formerly performed by human labour (Edquist and Jacobsson, 1988; Kaplinsky, 1987; De Meyer et al, 1989).[23] Reductions in cost are not, however, of the same rate as those in employment, as there is the need for remaining workers to become multi-skilled and to take-on enhanced responsibilities over the production process, which necessarily must be accompanied by increases in wages, training or other labour costs. For instance, in the manufacturing of microchips the importance of engineers and technicians has increased considerably (Mody and Wheeler, 1990).

Inputs costs are also reduced. There is clear evidence showing that waste is minimised, that there is more efficient utilisation of material and that there are far less rejects due to poor quality, leading to significant cost reductions in inputs (Bessant, 1991; Haywood et al 1991; Hoffman and Kaplinsky, 1988; Kaplinsky, 1991).[24] Again, like in the case of labour costs, overall input cost reduction is a net effect as, as Sheridan (1988) points out, the costs of some individual components rise due to inventories building up in the components firms, less competition that translates in higher parts prices and, occasionally, failure to deliver on time. There are also significant cost savings in space and energy. The physical sizes of buildings, the distances that products have to move inside the factory, and therefore the energy requirements, all fall (Haywood et al, 1991; Hoffman and Kaplinsky, 1988; Kaplinsky, 1991). Finally, there are cost declines in inventory carrying and the associated working capital required to finance operations.[25]

Not all costs, however, drop. Although machine utilisation ratios increase, total capital costs are so high that they prevail over productivity gains at the same level of output than with 'old' technologies. Despite the reduction in the cost of microchips and computers and their increase in power, the cost of the production equipment that uses semiconductors and computers is still higher than with 'old' technologies. For instance, Edquist and Jacobsson (1988) show that the average cost of a modern numerically controlled machine tool is twice the cost of a conventional one. Other flexible technologies, such as CAD/CAM, robots, and FMS systems, although they do not have an equivalent 'old' technology benchmark to compare with, imply a much larger effort in terms of the investment requirement than the equipment they replace. Furthermore, for an FMS system to operate properly there are a number of related investments in fixtures, jigs, tools and system planning and maintenance that are essential (Haywood, et al, 1991).[26] Besides, it is not only the cost of the equipment that is increasing but also, because of the rapid pace of technological change, plants and equipment are becoming obsolete much more rapidly than before (Kline and Rosenberg, 1986).

If capital costs are so high that they outweigh reductions in all other costs and higher utilisation ratios, then the obvious alternative is to increase the level of output, of whatever varieties the market accepts, and reduce unit costs until optimal scale is reached. Higher levels of plant output in the industries reviewed, suggest this is how plants are adjusting to 'escalating' capital costs. In this way, NT enable both flexibility and lower unit costs but at the price of 'scaling-up'. The unit costs of achieving flexibility are so high that they can only be amortised if plants produce at higher levels of output.

According to Carlsson (1991), Edquist and Jacobsson (1988) and Krinsky and Miltenburg (1991), the main justification for investment in most AME by many firms is strategic, i.e. to advance firms' technological capabilities and be more responsive to market demands, not so much to reduce unit costs. In fact, there are some cases where total unit costs have risen as a consequence of investment in new machinery. This was more than compensated by higher returns due to the attractiveness of the new products being sold, as consumers were willing to pay premium prices for better quality or more variety (Carlsson, 1991). However, Williams et al (1987) and Jaikumar (1986), while accepting that this type of reasoning may be necessary in the case of early adopting firms, argue that it is only high cumulative volumes of output that eventually justify investment in high-tech equipment such as FMS. They add that it is only in Japan, where FMS are continuously being operated on a three shift basis and near to their limit in capacity, where 'normal' payback periods of three to five years are being achieved. Firms in other countries, such as the US or the UK, with poorer FMS use performance are getting into serious financial difficulties.

Some may argue that one way of avoiding the very high costs of equipment is concentrating only on the new organisational changes that are considerably cheaper than the hardware costs (Sayer, 1988; Schonberger, 1988; Womack et al, 1989). Indeed, James and Bhalla (1991) indicate that NT do not have to be introduced simultaneously. While this assertion seems particularly relevant for cases where adoption does not involve new plant construction, it must be pointed out that in very few of the studies reviewed we found only organisational modifications being introduced. They were always paralleled, or closely followed, by some sort of investment in 'hardware'. Besides, as much of the very 'modern technology' literature points out, many of the cost savings deriving from NT depend on the 'complementarities' and 'synergies' of the various techniques. Introducing them piece-meal may lead to, albeit useful, only minor cost reductions.

Before moving on to the discussion of firm scale, two last points arise on the relationship between some of the NT and changes in optimal plant scale. It is sometimes argued that the 'miniature' nature of some of the new microelectronics techniques, such as computers, CAD and computer-controlled machine tools, permits efficient production at substantially smaller scales of output (see James and Bhalla, 1991, for a critical review of this argument). It seems worth stressing that greater divisibility of capital, i.e. availability of some technologies in relatively small sizes, does not necessarily entail a fall in efficient output. It only means that small-scale firms may be able to use these technologies. While the adoption of these NT may make small firms more competitive in terms of quality and speed of response to the market, as far as efficiency is concerned, it may at best reduce the cost penalty of producing at 'suboptimal' levels provided greater divisibility of capital leads to the 'flattening' of the cost curve. Whether it leads or not to 'de-scaling' will depend, as we have argued before, on the combination of technical and cost factors. In fact, at certain costs, even these technologies may result in higher, rather than lower, optimal scales.

It is also argued that as NT allow plants or firms to diversify products, this leads to 'de-scaling' because plants or firms are now in the position of catering for the far larger variety in consumer preferences. According to Kaplinsky (1991):

> "Moreover, as market conditions became more competitive, producers played an active role in fostering consumer dissatisfaction with unchanged products. As a result, the last two decades have seen a significant change in consumer preferences in IACs. Price is now less important than quality.
>
> ...these changes in consumer preferences have not occurred autonomously and have been facilitated, and often fuelled, by simultaneous changes in production philosophy and technology which have made it possible to widen consumer choice." (pp. 148-149).
>
> Consumer preference for more diversified products (which is inherently descaling of product runs, and often also has descaling implications for plant size)..." (pg. 154).

Unfortunately Kaplinsky does not elaborate on the mechanisms through which NT and demand for variety lead to de-scaling. In other passages and earlier writings such as Kaplinsky (1984) and Hoffman and Kaplinsky (1988), he suggests that NT are descaling in 'plant' terms because plants previously producing one good at a specific level of output can now produce the same level of output but in larger variety. But, it does not follow that because product scales fall so will plant scales. As we have indicated earlier, the key determinant of product scale is the setting up and change-over costs, which are only one of the factors affecting scale at plant level. If what he is referring to is that smaller scale plants can now be set up to cater for specific markets prepared to pay higher prices for better quality and distinct products, it must be stressed that producing at lower scales but at higher costs --presumably the reason for higher prices--, is simply not de-scaling.

Second, the capacity of small-scale firms to enter markets created by differences in consumer preferences is not necessarily due to NT. As Pratten (1991) points out, the main source of competitive advantage of small firms is, and always has been, the development of new products for which the market may be limited and the production or sale of products for which service is essential. Hence, supply and demand factors are confused in Kaplinsky's view.

4.3 The Firm Dimension of Scale

Kaplinsky (1990a) argues that one of the major effects of the introduction of NT is the reduction in the need for intermediate levels of management, which presumably will be accompanied by a fall in office and general maintenance staff, office space and the resulting office running costs. He points out that these savings will be far outweighed by the "simultaneous increase in the research-intensity of production and the growing market-intensity of sales." (pg. 163) so that there will be a firm 'scaling-up' effect. Although Kaplinsky does not elaborate fully on this issue, what he is essentially arguing is that the increases in 'fixed' costs in research and development and marketing resulting from the introduction of the new flexible technologies are such that they require higher levels of total firm output to minimise average unit costs.

4.3.1 Research & Development (R & D)

Data from several sources show an increasing trend towards higher expenditure in R & D. Figures by the OECD (1991b) show that between 1974 and 1984 expenditure in 'intangible investment', which includes R & D, advertising and software, increased in all countries from 2.6% of GDP in 1974 to 3.7% of GDP in 1984. This trend was present in all seven OECD countries which had comparable figures, with the US, Japan and Germany showing the highest increases. Patel and Pavitt (1991), focusing only on civilian R & D expenditure in OECD countries, find it increasing in real terms between 1967 and 1988, except for the United Kingdom. The figures also show that, following a slight decline in the early 1970s, real expenditure in R & D increased consistently in the 1980s. Between 1967 and 1989 annual expenditure on R & D in real terms in the automobile industry doubled in the case of American firms, trebled in the case of European firms and increased six-fold in the case of Japanese firms (Womack et al, 1990). Between 1976 and 1986 Japanese firms in the semiconductor industry were spending more than 15% of their sales on R & D while American firms doubled their expenditure to around 14% of total sales during the same period (Ferguson, 1988). Firms in the consumer electronics industries like Sony and Hitachi have been consistently increasing their R & D expenditure, which today stands at around 10% of total sales (Financial Times, 9/1/1992).[27]

Freeman (1982) considers the invention of the microprocessor as parallel to the development of the steam power because of its widespread impact on production. The 'chip' opened the door to many direct product applications, such as micro-computers, digital telephones and exchanges, fax, high definition TV, compact-discs players, computer-axial tomography, desk-top publishing, flight simulation equipment, precision control instruments and all the capital goods mentioned before, and, indirectly through the use of some of these products in the R & D of other innovations. The eventual application of semiconductors in sensory devices, which implies reproducing some of the human visual and tactile capabilities, and of microelectronics control equipment in the biotechnology industry, are expected to lead to another wave of major changes in manufacturing production (Ayres, 1991; Fransman, 1991).

Although it is difficult to make a straightforward link between the development of NT and rising R & D costs, there are a number of features arising from the NT that suggest they have had an important influence on this trend. First, they involve 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 (Mody and Wheeler, 1990). Second, for propietary reasons many corporations favour in-house expertise, or clearly defined agreements, which often leads to the failure to utilise outside ideas and therefore to duplicate work (Kline and Rosenberg, 1986). Third, NT involve the creation of 'radical' or 'never-before-seen' type of products. These products are in the technological frontier and therefore are both 'science-based' and the result of a lengthy trial and error process, a sort of 'guided empiricism': "One starts with all available knowledge and makes the first best estimate of a workable design, then proceeds to build it, test it, incorporate learning, redesign, retest, incorporate learning, and so on (sometimes ad nauseam)." (Kline and Rosenberg, 1986, pg. 298). As it is also a learning process, it normally implies a large number of unforeseen tasks and more time than planned or than that required for an 'evolutionary' innovation (Kline and Rosenberg, 1986).[28] The fact that products have become increasingly more complex technically makes their development even more difficult. According to Ayres (1991), early automobiles were largely based on bicycle technology with the addition of a crude internal-combustion engine and required between 1,500-2,000 parts. Today's car requires more than 30,000 distinct parts. An industrial power circuit breaker evolved from a simple product to one requiring today 1,300 parts. He adds: "Roughly speaking, consumer products increased in complexity by a factor of 10-15 from 1830 to 1900 and by another factor of 10-15 from 1900 to 1980" (pg. 4).[29]

A fourth feature explaining rising development costs follows from the very successes of previous innovations and has to do with the pressures for a reduction in product development time resulting from the increase in flexibility and speed of the manufacturing process. One of the major consequences of the introduction of NT to manufacturing production has been the reduction in 'throughput times', i.e. the period required to manufacture a specific product from the moment production starts to when it finishes. In addition, there has been a fall in the time required either to source components from suppliers or to deliver goods to customers. The upshot of increasing manufacturing speed is that the product development time-cycle has also to fall. Rather than taking several months or years to develop, new products are and will have to emerge from R & D departments much faster than before. Furthermore, in a context of increasing flexibility, firms that can bring new products and/or can continuously modify previous innovations enjoy a competitive advantage over other companies. For Stalk (1991) one of the major advantages of Japanese manufacturers is the significant decreases in product development times, including reductions of one-third in products as varied as TVs or custom plastic moulds, and of one-half in automobiles. Goldhar and Schlie (1991) also mention cases of industries where product development cycles are already taking up only one-fifth of their former time. This has required hiring new personnel with different and specialised skills in fields related to electronics, electrical engineering, programming and systems design as well as investments in more advanced design equipment.

Another source of increasing R & D effort is in adapting and modifying the production process to the NT so that lower production costs can be achieved. While this has always been a central activity of the firm, the adoption of NT requires such efforts in a number of new areas. One area where considerable effort and investment has been put in, even for less sophisticated products, is product-design, including "design for assembly' or 'design for producibility' techniques. These techniques consist not only in designing a number of standard and interchangeable parts, but completely redesigning all parts and products and most of the productive process with the help of computers capable of modeling physical processes. In this way the number and complexity of components can be drastically reduced and products can be easily built with as fewer jigs and fixtures as possible. Although it still does not totally avoid testing of certain components and products, it reduces its need as different shapes, materials and properties can be examined on-screen: "a designer can not only draw a component on screen but prompt the computer to model and test the feasibility of its features, in the manner of a business planner using an electronic spreadsheet to play 'what if' games" (Whitney, 1991, pg. 128). Design for assembly and design for producibility techniques require detailed written knowledge of the production process and a capacity to write complex software packages which, in many cases, are factory specific, and therefore ask for an in-house software writing team (Bolwijn et al, 1986).

The second process area that requires considerable research effort is the operation of NT. A typical FMS not only involves careful pre-installation work but also considerable research on production interfacing and organisation (Haywood et al, 1991). The pre-installation studies required to introduce an FMS may take up to two years if mistakes are to be avoided. Getting an FMS to operate correctly involves solving complicated integration and communication problems and requires prior experience in handling hi-tech equipment, which is only possible in experienced engineering and R & D departments. For Haywood et al. (1991), this is an additional reason why only large firms are experimenting with FMS or CIM.[30]

However, it is in the integration of design, manufacturing and some of the other functions of the company where the difficulties are more acute and the needs for larger investment in development even higher. One of the main problems with CIM users is that there are no turnkey capabilities, i.e. one firm supplying the whole range of products and services required in a standard package (Bessant, 1991). CIM installations are highly specific combinations of technology, involving different elements for individual firms. Particularly difficult is the software for linking elements in a network so that pieces of equipment can 'talk' intelligibly to each other. Although this will probably be attempted both by outside suppliers and specialist consultants, it is only those firms that have and expand their specific capabilities in the areas of system integration and software who will be capable of succesfully adapting CIM to their individual conditions. Furthermore, the potential gains of 'learning by using' will accrue only to those enterprises that attempt to deal with the problems of integration. Indeed, Bessant (1991) points out that it is the main users, both the computer equipment suppliers themselves and other early users, that are developing the necessary expertise to address the problems involved.

Key factors underlying increasing R & D costs are the additional employment required, particularly of scientists and skilled personnel, and the computer and control equipment and software necessary for these activities. As far as employment is concerned, firms using NT are increasingly demanding scientific personnel, computer specialists and academics for their R & D departments (Dostal, 1988). Demands also include social scientists, as R & D activities have not been 'limited to product and process innovations but have included social innovations.' (Dostal, 1988, pg. 38). In addition, a large number of support staff will be necessary, including highly-qualified research assistants, data processing specialists, blue-collar workers for laboratory activities, R & D managers and auxiliary personnel. In West Germany, the only country that Dostal found had a breakdown of R & D employment, between 1973 and 1980 it increased by 5% to 2.2% of total employment.[31] An OECD (1991b) study shows that the United Kingdom's industrial sector had increased its stock of engineers by 25% since 1982. The same report also points out that, given present population trends and the requirements of scientific and technological personnel, particularly by industry, there is the potential for an overall shortage of scientists and engineers within the next years.

One important caveat regarding the relationship between NT and rising R & D costs refers to the role of the imitator. While firms heavily engaged in product and process innovations will have to confront escalating development costs, this will not necessarily be the case of imitator firms, or at least not to the same extent.[32] Moreover, as Kline and Rosenberg (1986) indicate, the dangers of failure in the development of the more technologically complex products are so high that: "the earliest Schumpeterian innovators frequently wind up in the bankruptucy courts, whereas the rapid imitator, or 'fast second', who stands back and learns from the mistakes of the pioneer, may experience great commercial success." (pg. 301).

4.3.2 Marketing and Distribution

NT will not only increase R & D costs but will also raise marketing and distribution costs because of the larger variety of goods and the new and more information-intensive approach to selling.

Chandler (1990) argues that, initially, large manufacturing firms marketed their goods through independent companies which could achieve marketing scale economies. Only after reaching a minimum size did they expand into marketing and distribution so that gains could be made from volume distribution. A sales force was then organised to "concentrate full-time on advertising, canvassing for customers, assuring delivery on schedule, and providing installation, service and repair, customer credit, and other services for their particular line of products" (pg. 30-31).

Under NT, establishing a network of marketing and distribution integrated to other functions of the company becomes a necessity from very early stages of application. Speed of response in manufacturing and the capacity to introduce new products and anticipate the market are today much more crucially dependent on market intelligence and continuous information, which in turn require purpose-built channels, infrastructure and specially trained personnel. This is particularly important if specific growing market segments or trends are to be identified. Often, these sales and distribution networks must extend beyond national borders and, as a result, the amount of information that has to be processed increases. Increasing information, in turn, normally requires a major upgrading of the equipment necessary to handle and transfer data.

One particularly illustrative example comes from Benetton, the successful Italian fashion firm. According to Belussi (1987, 1992), the retailing system of Benetton is fundamental to the firm's NT adoption strategy. Benetton had in 1985 around 2400 shops all over the world. Around 200 of these shops, located in four strategic markets, are the 'antennae' of Benetton's information system. They provide information on a daily basis about each item sold, including model, colour, size, and so on. This information is then fed into production and design enabling Benetton to respond to market changes in about ten days. To do so, however, the company had to equip its 200 key shops with advanced cash registers, telecommunications links with a central computer and the necessary software and hardware support, which implied a major investment effort.

The new flexible technologies also lead to additional advertising costs. Insofar as advertising gives the customer information and communicates the availability of new products, more product variety implies having to provide details of more products. In the case of Benetton, Belussi (1987, 1992) reports that the company experimented with different ways of reducing costs in this area. It eventually came up with the idea of not advertising individual products but specific characteristics like colours, types of clothes or brand, but doing so required national and international campaigns through the widest possible media. As a result their advertising costs have been increasing continuously and exceed by far those of R & D --2.8% of sales as compared to 0.5% in 1984. This trend is not specific to the garments industry but to most mass-consumer industries introducing NT (OECD, 1991b).

4.3.3 Management

One of the main problems of large size enterprises using old technologies has always been the tendency towards bureaucratisation. Decision-making and the coordination of firm's activities grew increasingly complex and, as a result, hordes of middle level managers and support personnel were required (Scherer and Ross, 1991). Eventually the M-Form of organisation emerged to ease the managerial task and establish hierarchies that were capable of handling functional, product and regional requirements together (Chandler, 1990). For the 'modern technology' literature, in contrast with previous technologies, NT reduce considerably the number of hierarchical levels within the firm, as less mechanisms of control over workers are required given their reduced number and because of the responsibility-oriented system of production. Also, insofar as some of those middle managers were mainly responsible for organising and passing on information to senior managers, the adoption of information technology reduces even further the need for middle layers (Watson et al, 1987).

There is considerable controversy as to the employment impact of NT at managerial level. Some argue that the reduction of middle management layers is reducing employment at this level but others say that the increasing amount of information available to senior management is just leading to more questions being asked which requires more, rather than less, middle managers (Watson et al, 1987). Dostal's (1988) study on employment patterns and trends in the Federal Republic of Germany throws some light, albeit limited, into the employment changes at managerial and office level. While the share of 'simple' office work, such as typing or operating copying machines, dropped between 1973 and 1980, the share of new employment categories, such as 'integrated file processing' and 'preparation for decision making' carried out by trained specialists, increased so that the net effect was an increase in the share of employment in general office work. Employment at the managerial level increased during the same period due to rises in 'decision-making', and particularly in 'policy-making' managers. Obviously, this evidence can hardly be generalised but it suggests that as management becomes an information intensive function there are increasing needs for information support activities which may compensate for job losses in other areas.

Whatever the effect on labour costs of employment at managerial level, it is in training where managerial costs are expanding. Many of the skills required for the efficient use and application of NT are learnt at work through special in-house vocational training or together with technology suppliers and on-the-job training (OECD, 1991b). The use of more sophisticated business equipment requires acquiring and enhancing new skills. Furthermore, the evidence indicates that training is being concentrated at the highest managerial levels within firms (OECD, 1991b).

However, it is in the software and hardware required to support management where the increase in costs are the greatest. Although the cost of some types of equipment like computers and certain software packages may be falling, overall expenditure in office automation is 'rising'. To some extent this is due to growing office innovations, such as fax, presentation computer graphics and laser data storage facilities. It is also the result, not only of the costs of computers but that of peripherals and software associated to them.[33] Appart from the by now well established wordprocessor and spreadsheet software, there is a variety of business specialised software packages for accounting, data-management and, above all, 'expert-systems'.[34] More importantly, the rate of obsolecency of hardware and software is very high, so offices are constantly replacing or updating them.

Finally, there is the cost of re-organisation. Although once an effective organisation is in place it will no longer be necessary to incur these types of costs, in the initial stages, the introduction of NT may lead to significant re-organisation costs. A report by OECD (1991b) mentions that some Swedish industrial firms are devoting around 25% of total labour costs to re-organisation and new coordination activities. Kaplinsky's (1991) study of the reorganisation of Lucas LFS also found restructuring costs arising from the shifting of equipment and lost management time.

In sum, at firm level, the introduction of NT is producing a similar effect as at plant level because of its cost effects on activities such as R & D, marketing and management. There are reductions in employment in some 'old' technologies related areas. There are notable increases in the productivity of the resources and also economies of scope, as many of the R & D and marketing personnel and facilities are being used for a greater variety of products. But these gains are coming at the price of increasing R & D, marketing and management 'fixed' costs. As at plant level, higher costs imply larger volumes of output to be efficient. Achieving this may be done either by increasing the output of existing plants so that they take into account these higher 'fixed' costs, or alternatively, through the establishment of other plants so that all operate at each's plant production optimum and costs are 'diluted' over total aggregate output. In both cases, additional considerations such as transport or infrastructure costs, and increasingly, communication costs, will have to be included in deciding whether new plants should be established and where these should be located.

There are a number of intermediate solutions like becoming imitators or avoiding having an internal sales network or purchasing sophisticated telecommunications equipment. But while this may be indeed the only options available for many firms they imply that, as in the case of plants, not all the 'complementarities' or 'synergies' associated with NT may be exploited. Furthermore, in some science-based or mass consumption industries, where innovation, learning and/or market intelligence and knowledge are crucial for survival, firms may not have a choice but to modernise totally, and therefore scale-up, if they want to remain competitive.

5. SOME ADDITIONAL CONSIDERATIONS: 'NEW INDUSTRIES' AND 'THIRD ITALY'

Changing focus slightly away from the alleged 'de-scaling' impact of NT, we will now move on to the question of whether NT are of any benefit for small scale firms. A number of authors within the 'modern technology' literature focus not so much on the impact on optimal scales but rather on how NT may allow small firms entry to new industries or may reduce small-scale related limitations.

5.1 'New Industries'

One way NT could offer opportunities for the development of small firms is by allowing the emergence of industries which are particularly suitable for small scale production. A relevant example comes from the semiconductor industry and refers to the design of application specific integrated circuits (ASICs) (Hobday, 1991, 1990b). ASICs are customised or semicustomised integrated circuits (IC). Until 1984 producers of information technology systems had to purchase standard IC and combine them in the way that suited their purposes. ASICs allowed them to have integrated circuits that embodied the functions of the combined circuitry. Since then, the ASICs business has been the fastest growing segment in the semiconductor industry on account of increasing demand by the consumer electronics, office automation, computers, telecommunications and capital goods industries, which saw in ASICs the possibility of producing tailor-made, better-performance, cheaper products. Underlying this expansion was the introduction of electronic design automation (EDA) technology. It consists of specialised software packages and computer workstations that allow the independent design of ASICs, which in turn has permitted the emergence of a thriving 'decoupled' industry, much in the same way the software industry emerged from the computer industry in the 1970s.

This new design industry is particularly attractive for small-scale firms. Hobday (1990a, 1990b) gives three reasons for this. The growth of the IC industry depends to some extent on the diffusion of its products to smaller users and to firms with little experience in semiconductors. Large IC producers are not structured to produce for these users, whereas independent ASICs designers could provide design and consultancy services adequate to their specific needs. Second, the 'decoupling' of design from manufacturing has lowered technological and financial barriers to entry to this market, allowing skilled individuals, distribution outlets and software firms to enter the design industry. Finally, small-scale designers could be of use as specialist technical support for large users and producers of ASICs.

No doubt NT will allow the development of new industries open to small scale firms. The development of the aircraft industry eventually gave way to the emergence of an independent design sector (Rosenberg, 1984). There is a large number of small-firms of architects and engineers operating around the construction and engineering industries. Hobday (1991, 1990b) also points out how the skill-intensive software industry became an offspring of the computer industry. The real issue is whether NT will give rise to more small scale industries than before. In other words, will NT generate a significant number of 'new' industries with low technological or economic barriers to entry? Our earlier discussion suggests this will not necessarily be the case, particularly in manufacturing. The investment requirements for equipment and the increasing development and marketing costs suggest higher rather than lower technological and economic barriers to entry. A case in point is the biotechnology industry, where the basic and applied research was initially done by several small-scale firms that later found themselves without the finance nor the experience to undertake the manufacturing of their products (Office of Technology Assesment, 1991). In the telecommunications industry the introduction of new microelectronics-based product technologies has facilitated considerably the manufacture of smaller private exchanges. Although this has allowed more entry and competition in this particular market 'niche', it has not been by smaller firms but larger ones from industries with similar product design skills, as the main technological barrier of the new exchanges has switched to design (Hobday, 1990a).

Second, even if there was a larger number of 'new' industries it is not clear that they will be ones where small scale firms will be 'predominant'. The trajectory of the software industry is quite illuminating in this respect. The industry did indeed emerge in the early 1970s as based on small-scale firms, but by the late 1980s it was already dominated by a few large and medium size firms, although there was also a large number of small firms meeting very specific customer demands (Hobday, 1991; Schware, 1989).[35] A similar process seems to be unfolding in the ASICs design sector, with both major users of ASICs and major semiconductor producers establishing or taking over a large proportion of design companies. Mody and Wheeler (1990) point out that a major semiconductor producer, Texas Instruments, is already opening facilities next to users in most countries to help them in the design of integrated circuits tuned to their specific needs, which are then manufactured in one of Texas Instruments plants. Nevertheless, Hobday (1991) also shows evidence of an independent design sector accounting for around one-fifth of the market both in the US and Europe. Thus, the trend in both industries suggests that, even in the design sector, as the 'new' industries mature they will be characterised by a small number of large firms concentrating on the 'core' products and a large number of small firms catering for specialised needs or other small firms.

5.2 Third Italy

Another way NT can benefit small firms is by allowing them to network so that jointly they can achieve scale and scope economies unavailable to each one of them individually. One of the most relevant examples comes from the region known as 'Third Italy', the northeastern and central area of Italy, where clusters of firms using a combination of 'hardware' and organisational techniques have been capable of increasing production, exports and quality even during periods when economic growth in other areas of the country and the world was stagnant.[36]

In essence what characterises the 'Third Italy' is the existence of clusters of successful small scale craft-based family firms across wide geographical areas and industries. According to Inzerilli (1991) the best way to understand how these clusters operate is by imagining a ’large-scale’ corporation whose components are independent firms. All the major functions of the organisation, from purchasing to production and marketing, are assigned to individual firms. Each function can be performed by a variety of firms, so that firms do not necessarily perform the same function all the time. One of the firms, normally the marketing one, performs the planning and coordination function and therefore operates as a ’head’ firm although it does not have any contractual power to excercise control over the other members of the ’corporation’. Furthermore, individual firms participate in several ’corporations’ at the same time.

The ’corporations’ of each region specialise in a specific industry. The most important are textiles, clothing, leather, shoes, furniture and also some more ’modern’ ones like mechanical engineering. The productive process is subdivided in as many stages as possible so that individual firms can specialise in each stage (Dei Otai, 1991; Inzerilli, 1991). Labourers tend to be highly skilled so they can easily adapt to changes in equipment, to the introduction of new techniques, and to the manufacture of new goods (Inzerilli, 1991). Depending on the industry or the function, individual firms equip themselves with multi-purpose machines and CAD/CAM, CAD cutters, electronic control equipment and/or computer numerically controlled machines or looms (Colombo and Mazzonis, 1984; Inzerilli, 1991; Piore and Sable, 1984; Zeitlin, 1992). In recent years there has been an increasing use of telematics hardware and software including computers, networks, electronic mail devices, databanks and technical languages for computer communication. Increasingly, firms are being linked through telematics devices and this is becoming one of the main means of communications between them (Antonelli, 1988; Rullani and Zanfei, 1988).

’Corporations’ are ’glued’ together on the basis of longstanding ties of trust and cooperation between individual members. For Dei Ottai (1991) this means that there is no need for formal contracts or any other contractual form, reducing transaction costs. It facilitates coordination across phases of the productive process, specifically in terms of the volume and characteristics of inputs and products. It encourages collaborative relations between employers and employees, which is particularly important in wage negotiations and to avoid labour disruptions. And finally, it eases the diffusion of technology and know-how and stimulates innovation, as ideas from others are normally taken up and explored. However, cooperation does not mean lack of competition, as there are always several firms capable of undertaking any particular task and individual firms are very conscious of this fact. Ease of entry and exit also ensures competition.

By participating in several ’corporations’, individual firms maximise capacity utilisation as, when demand is low for a particular product or corporation, they switch to the production of another good for another corporation. The capacity to switch production also leads firms to reap economies of scope, which can be very large in fashion-related industries. A large overall ’corporation’ volume of output allows to engage in research, development and marketing activities necessary for growth, reducing the disadvantages of individual small firms vis-a-vis production from low-wage countries and/or large firms (Dei Ottai, 1991; Inzerilli, 1991).

The ’Third Italy’ case illustrates some of the potential benefits NT can offer small-scale firms. Apart from saving on some inputs costs, the use of NT in production should improve the quality of the goods, so there should be gains on this account as well. The use of telematics should also enhance production scheduling and inter-firm coordination, which, together with more access to the specialised marketing, prices and financial information available on-line, should increase the benefits for participating firms. Nonetheless, there are a number of cautionary points that bear emphasising regarding the general significance of this experience and its applicability to small firms in other contexts.

One first conceptual issue that arises from the 'Third Italy' experience is whether these 'corporations' are merely a collection of small independent firms or they constitute in some fundamental way a new and different institutional arrangement where the key to success is organisational unity rather than diversity or independence and therefore the 'size' of the 'corporation' and not that of its individual constituents is the proper unit of scale. Mody (1991) points out that the theory of the firm has typically maintained a sharp distinction between market and non-market --or hierarchies-- transactions. Firm alliances, which in Mody's view combine elements of markets and hierarchies as participants, do not give up their identity but do not deal with each other through the market either, and may therefore be considered as a potential 'new' type of arrangement. The innovation literature has already raised the issue of new organisational forms and has developed concepts such as 'network organisations', 'network firms' or simply 'networks', aimed at grasping some of the essential characteristics of sustained supplier-user relationships, regional agglomerations and international strategic technical alliances (DeBresson and Amesse, 1991; Freeman, 1991; Imai and Baba, 1991; Teubal et al, 1991). 'Networks' are seen as: "a loose form of an inorganic and decomposable system. As in a system, one assumes that there is more to the network than the sum of its interacting components. In other words, the network assumes positive --or negative-- synergy (networks have 'super' or sub-additive' properties." (DeBresson and Amesse, 1991; pg. 364). As the firm is seen in this literature in its Schumpeterian sense, i.e. as a combination of resources resulting in innovation, then the 'Third Italy' regional clusters may also be considered as a 'new' type of firm. Indeed, several authors are already applying the concept of networks to the Italian experience. Antonelli (1988) and Belussi (1992) argue that the 'Third Italy' is far less about the success of small firms but about how numerous small firms turn into a 'big firm' to compete successfully, domestically and internationally.

The second comment refers to the extent to which the 'model' conforms to reality. Amin (1989) and Amin and Robins (1990) argue that the actual situation in the region is far from similar to the description being presented by some of the literature. There are areas, like Prato in Tuscany or Bologna and Modena in Emilia Romagna, which generally correspond to the description in the literature but there are others, like Veneto or Marche, where the dynamism and the distributional effects from it are not precisely those highlighted by the 'model'. An important element of 'success', in the latter, has been low wages, poor working conditions and lack of social security for labourers i.e. 'sweatshop' type conditions. Women and ethnic minorities have been especially affected although some new opportunities have also opened for them (Mitter, 1992). Tax dodging has also been an important factor underlying firm performance in some regions (Amin, 1989).

Power relations between firms also vary. Storper and Harrison (1991) point out the existence of different types of relations of power and structures of decison making or 'governance structure'. These range from one where there are no 'leading' firms, like in the region of Prato, to another, in the Veneto area, where some 'leading' firms exercise a decisive influence or even dominate the internal operations of other, normally smaller, firms. In Veneto, for instance, many small firms operate as simple subcontractors, particularly of large firms like Benetton, resulting in lower revenues and longer working hours to meet the very short production deadlines set to them (Belussi, 1992).[37]

The third remark regards the long-run sustainability of the ’model’. Amin and Robins (1990) argue that the ’Third Italy’ may be a temporary or transitional phenomenon which may be succeeded by new waves of concentration of ownership by the most successful or ’foreign’ --to the region-- firms. They point out at the recent increase in takeover activity which has been accompanied by rising vertical integration in areas like Emilia Romagna, and a general slowdown in the uptake of technical innovations by all but a few small firms in Tuscany, as the starting point of a process of restructuring that threatens the survival of small firms. Furthermore, they add that many of these firms are increasingly becoming part of large multinational corporations which focus on finance, marketing, distribution and R & D.

The fourth related point regards the response of large scale firms to enhanced competition by smaller --and larger-- firms. While NT offer small scale firms the possibilities of networking and achieving scale and scope gains, it must be taken into account that these options are also available to large scale firms. As the literature on innovation illustrates (DeBresson and Amesse, 1991; Freeman, 1991; Imai and Baba, 1991; Teubal et al, 1991), networks involving large firms have also developed. It has also been shown earlier in this paper that large firms are increasing in flexibility. Thus, potential gains in competitiveness of small scale firms vis a vis large ones could be largely neutralised.

Finally, James and Bhalla (1991) point out that the ’Third Italy’ experience has several features or preconditions that may not be reproducible elsewhere. To begin with, there may be a lack of the ’communal’ ties that characterise this experience. While these ties may be present in other countries, they seldom have the strength they have in the ’Third Italy’. Second, there may also be a shortage of community institutions, such as banks, training centres, cooperatives and social welfare provisions, that facilitate the emergence of a thriving small scale sector. Third, unlike Italy, government institutions, local or national, may be unwilling or uncapable of providing support for the adoption and utilisation of NT. Particularly in developing countries, governments have tended to prefer large-scale establishments or simply have not had a technology policy aimed at small-scale industry. Fourth, in the case of some developing countries, there may not be the financial resources to invest even in the relatively cheaper NT. Fifth, in certain countries or areas, access to raw materials and spare parts may be precarious and/or there may not be the communications infrastructure required to operate the NT. And finally, in the ’Third Italy’ case, the complex information systems used were facilitated by the fact that firms were at relatively ’close’ distance to their markets, which are located in developed countries. This clearly would not be the case for developing countries’ small firms.

Schmitz (1990) also raises the issue of, albeit qualified, the particular historical process through which this region has gone through: "..., industrial success can also be explained as a result of a long process of learning. Indeed, the emergence of a professional culture and of networks of small firms cannot be explained without reference to the region’s economic history; but it remains unclear how much weight should be given to the historical factors" (pg. 266). In addition, he mentions the question of differences in labour market conditions between Italy and other countries, labour surplus as opposed to labour shortages, that may limit the application of NT. Variations in skills between countries may be another factor which makes replicating the ’Third Italy’ experience difficult.

6. CONCLUSIONS

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', and, more generally, supply and demand factors. It also assumes that firms will respond to capacity under-utilisation problems by reducing capacity and output, rather than by adjusting product range, especially if the capability to do so is available. It also fails to see the links between the product, plant and firm dimensions of scale.

The evidence reviewed showed that there has indeed been a reduction in setting up times and change-over costs and that this is one of the main factors explaining a relatively larger variety of products. However, at plant and firm level, the evidence tilted strongly in the direction of increases in optimal scale mainly due to the fixed capital investment, R & D, marketing and management requirements associated with NT. In other words, to achieve flexibility at product level and hence reap economies of scope, plant and firm scales have to increase. Although there are a number of intermediate solutions to reduce these costs, the complementary nature of the NT and the emerging competitive pressures, particularly in science-based and mass consumption industries, may make any alternative other than full automation a source of competitive disadvantage.

That plants and firms adopting NT will scale-up does not mean that there are no opportunities left for small scale firms. One specific advantage of NT is that they allow small firms to reduce quality differentials with large ones, traditionally a limitation on competition by small firms. In industries where cost differentials with larger firms are not too high, then smaller high-technology firms may be able to compete successfully by improving on service. In addition, NT are giving rise to some 'new industries', which, at the initial stages, offer entry opportunities for small scale firms. However, it was also stressed that some of the flexible capabilities of small firms have also been made available to larger firms.

Opportunities for cooperation, communication and coordination of small firms may also be heightened by the adoption of NT. This may help them overcome some of the problems related to the very high costs of R & D and marketing and enhance their competitive capacities. However, the possibility of generating a dynamic small-scale sector and whole regions based on small firm production that play an important role in local industrialisation and national growth may require some preconditions that are at the very essence of the process they want to initiate.

In sum, NT are neither a blessing nor a curse for small scale firms. They open some opportunities for their development but at the same time create new constraints on them. As always, the most innovative and successful small scale firms will grow to overcome their initial size. The others will have to continue to rely on product differentiation and quality of service as their main competitive weapon.

ENDNOTES

1. Length of production runs needs not coincide, in fact it rarely does, with the time period in which plant scale is measured.
2. Scherer et al (1975) point out that, when production is not on a strict to-order basis, decisions on how long a production run should be involve a trade-off between minimising unit set-up costs against minimising inventory carrying costs, which necessarily build up when demand is unknown.
3. According to Bessant (1991), during the period it took to changeover Ford lost US$ 200m, was forced to lay out thousands of workers --60,000 in Detroit alone--, had to scrap 15,000 machine tools and rebuild another 25,000, and lost its market leadership to General Motors.
4. For Ayres (1991), Kaplinsky (1990a) and Piore and Sable (1984), the combination of the equipment available and the nature of demand results in the production of goods in different batch sizes. Where the equipment is of the small, general purpose, stand-alone type and demand is customer specific, i.e. highly differentiated, then unit or small batch production results. Where the machinery is mostly dedicated, the transfer between work stations is automatic, and demand is undifferentiated and price responsive, then large batch 'mass production' emerges. Where specialised machinery coexists with a considerable amount of manual handling and tuning-up or where the transfer mechanism from one work-station to another is not automatic and demand is both differentiated and/or price responsive, then middle size batches follow. There is considerable debate as to the quantitative and qualitative significance of each type of production.
5. Tribe and Alpine (1986) have recently criticised the validity of the 0.6 rule on grounds that there are: "significant discontinuities in the value of the coefficient within the range of scales'. An earlier criticism along the same lines was voiced by Gold (1981).
6. Economies of scope can be defined formally in the case of two outputs, q_1 and q_2, as follows:

$$C(q_1, q_2) \quad C(q_1, 0) + C(0, q_2)$$

7. Baumol et al (1988) and Bailey and Friedlaender (1982) point out several illustrative cases where economies of scope in production may be at work. The first one is the case of an input used in different stages of the production process. Once sheep is raised, it is generally cheaper to produce both wool and mutton than to raise sheep separatedly for each product. The second refers to indivisibilities of certain factors of production. In the light of a falling demand for cars, the use of a stamping machine for the production of light trucks as well as for cars may provide an economy of scope. The third example comes from the reuse of an input by more than one product, like the case of a firm that produces abstracts from journals. The firm produces three separate indexes of abstracts, including a general one, which contains all the information, and two specialised ones on the basis of the general one. A scope economy arises because the general index is freely available for the other two indexes. The final case comes from the economies of networking. Routing different flights using cheaper larger planes through the same airport and then combining passengers with the same destination in other large planes can lead to cost reductions in the overall journey.
8. Transray concavity in Baumol et al's (1988) terms.
9. Transray convexity according to Baumol et al (1988).
10. This is called in the literature ray average costs (RAC). For a detailed discussion see Baumol et al (1988).
11. Under the 'modern technology' heading we are including a wide body of literature associated with terms such as 'flexible specialisation', 'post-fordism', 'lean production', '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, 1989, 1990b, 1991a, 1991b; Acs et al 1990, Carlsson, 1989a, 1989b; Kaplinsky, 1984, 1990a, 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, 1990).
12. The new tools and equipment include computer numerical control machines (CNC); robots; computer aided design/engineering (CAD/CAE); computer aided manufacturing (CAM) i.e. the combination of CNCs with the monitoring and control of production process, especially the flow of material; automated

materials handling (AMH); automated guided vehicles (AGV); automated storage and retrieval (AS/RS); flexible manufacturing systems (FMS), i.e. the combination of robots, CNCs, AMHs, AGVs, AS/RSs and central computer control which coordinates all steps of the production line; and, computer integrated manufacture (CIM), i.e. the integration of all design and manufacturing capabilities and other business data into a single management system; and telematics, i.e. the integration of computer and telecommunication technologies.

13. Kaplinsky (1991) and Morroni (1991) point out that in some cases successful innovators had first to master a number of organisational innovations and, only then, could adopt the AME. Womack et al (1990) argue that the productivity gains of the Japanese automobile industry could have been equally achieved without the introduction of AME.

14. Among the most important organisational innovations are: Cellular Manufacturing (CM), the physical orientation of the factory into product oriented work centres; Group Technology (GT), the classification of families of parts according to similarities in their geometric characteristics, material or manufacturing characteristics; Just-In-Time production (JIT), the reduction of inventories by organising production processes to be more responsive to precisely timed customer delivery requirements; Quality-circles, teams of workers constantly evaluating quality; Materials Resource Planning (MRP) and Manufacturing Resource Planning (MRPII), integrated decision support systems for planning and controlling material handling and manufacturing operations, which provide automatic feedback with production, logistics, marketing and finance. Inter-firm innovations include close supplier-buyer relationships, i.e. the establishment of long-term financial and technological cooperative ties, which in some cases may involve single sourcing; well-defined purpose cooperation agreements between competing firms in areas such as price or product development; and, finally, the establishment of 'institutions of inter-firm cooperation', such as the German 'combines', the Japanese 'keiretsu' and the Italian 'consorzia'.

15. Drawing on Marshall, Marx and Smith, authors like Kaplinsky (1984, 1990a, 1991), Perez (1985) and Piore and Sabel (1984), see 'mass production' or 'fordism' as a way of organising production based on the principle that the cost of producing goods could be substantially reduced if machines replaced the human skills required for their manufacturing. This could be achieved by decomposing every handwork task into simple steps, each of which could be performed by a machine dedicated to that specific purpose. Greater machine specialisation meant a faster pace of work and far less craft labour, resulting in lower unit costs. This approached materialised fully early this century with the introduction, by Henry Ford, of the moving assembly line, which processed basic inputs in a "fixed sequence of steps using equipment specifically designed to produce a single standardised product in extremely large quantities for extended periods of time." (Milgrom and Roberts, 1990, pg. 511).

16. There is another type of flexibility that refers not to the capacity to switch between products but to the capacity of producing a single output at speeds that correspond more closely to changes in demand. The idea that there are variations in the elasticity of unit costs with respect to the volume of production was introduced by Stigler (1939; see also Carlsson, 1989a; and Pratten, 1991). Morroni (1991) refers to this type of flexibility as 'adaptability' to differentiate it from the multi-good situation.

17. NT have the added advantage that they reduce the uncertainty associated with variable demand (Talaysum et al, 1987). It is argued that, whilst until the 1970s consumers were satisfied with low price standardised products, rising income since has led to significant changes in consumer tastes and preferences. Increasing sophistication by consumers has fueled the demand of a wider variety of quality products. According to Acs and Audretsch (1990a, 1990b), Kaplinsky (1990a) and Hobday (1991), this trend is not only present in consumer industries but also in intermediate industries where the demand for differentiated goods is growing much faster than that of undifferentiated ones. By being 'flexible', producers can easily adapt to these changes.

18. Some authors use falling physical size indicators, like size of buildings or total area, as evidence of 'de-scaling'. These indicators are strictly meaningless from an economic point of view.

19. Ferguson (1988) points out that two-thirds of NEC's production, one of the largest manufacturers of semiconductors in the world, takes place on a single factory complex in Japan.

20. Apart from steel, Auty (1992) points at the production of ammonia as the only other industry where 'de-scaling' due to industry-specific technical change has occurred in the past. ICI developed a technology which produces competitively at 450 tons daily compared with 1,500 tons per day with the previous technology. However, he also points out that this represents a very minor proportion of the petrochemical industry.

21. A follow-up study carried out in the paper converting industry by the same authors reaches very similar conclusions except for a lesser reduction in labour costs, as it is not possible to integrate fully the production process and therefore some of the even newest machines still need to be constantly manned.

22.

Auty (1992) raises the possibility of plant 'de-scaling' not through the reduction of optimal scales of equal or similar products but through the substitution of products by completely different ones produced at lower optimal plant scales. He gives the example of the replacement of steel by engineered polymers that could be economically produced in plants of around 40,000 tons. However, it must be emphasised that there is very little evidence of this type of 'de-scaling' taking place in any significant way. Furthermore, it seems much too early to say what will be the scale of production facilities of inputs, which in many cases, are at experimental level.

23. In a study on the impact of NT on employment in 186 US, 214 Japanese, and 174 European large manufacturing firms in 1986, De Meyer et al (1989) found reductions of 47.6% in US firms, 76.7% in Japanese enterprises and 64.5% in European firms.

24. De Meyer et al's (1989) already mentioned study reports that around 55% of total manufacturing costs are accounted for by materials and components. Hobday (1991) puts the same figure at 70% in the telecommunications sector. The introduction of new materials, which include organic high-performance like plastics and elastomers materials; inorganic materials such as heat-resistent ceramics; metals and alloys with improved composition, structure and purity; composites materials including combinations of glass and resin; and, most microelectronic material, may have an impact over these types of costs. While these materials account today for only 5% of total material turnover they may take a much larger proportion by the end of the century (Cohendet et al, 1988).

25. According to Jelinek (1987), inventory reductions of 40% - 60% have been achieved by firms introducing JIT techniques. Another estimate quoted by Haywood et al (1991) points at savings in inventory carrying costs of no less than 50%.

26. The cost of FMS equipment, without additional parts, in 1986 was around US$2 to 3 million for the simpler ones, US$3 to 7 mn for the slightly more complex ones, and over US$7 mn for the more sophisticated ones (Haywood et al., 1991). The 'very high' capital equipment costs is repeatedly being mentioned as the main limitation to the adoption of new technologies by firms, particularly small ones, both in developed and developing countries (Acs and Audretsch, 1990a, 1990b; Acs et al, 1990; Ferraz et al, 1991; James and Bhalla, 1991; Pratten, 1991).

27. Scherer (1991) and Scherer and Ross (1991) mention some examples of very high innovation costs due to the complex nature of the products being developed: the clinical costs for a new pharmaceutical clinical entity in the US to be around US$ 100mn, the bringing into existence of the high definition television system costs at least US$ 700mn, and the development costs of a new long-range subsonic airliner were around US$ 3bn. The R & D costs of digital switching systems range from US$ 0.5bn to US$ 1.5 bn according to Hobday (1990a). Costs are even higher for non civilian projects.

28. Kline and Rosenberg (1986) also highlight the great uncertainty surrounding the innovation process, particularly that of the newest products as they argue that the degree of uncertainty is strongly correlated with the amount of advance of a given innovation.

29. Rising development cost also arise from the health, safety and environmental concerns resulting from a number of recent innovations, although this applies more to the pharmaceutical, chemical, biotechnology and nuclear products than to microelectronics-based ones (Kline and Rosenberg, 1986; Sharp, 1991).

30. In 1988 there were only 880 FMS systems installed worldwide and by the end of 1990 only around 1000 should be in operation (Haywood et al, 1991). The systems being used and developed are much simpler than what was originally promised and therefore the gains from them, although substantial, are not as high as expected.

31. Dostal (1988) also estimates that, given the requirements of R & D personnel in the next years, the Federal Republic of Germany will have a ratio of 1 R & D employee for 7 production workers in the year 2020 as opposed to 1 to 20 in 1973. He also points out that, although most academic estimates of the overall and industry-specific impact of NT on employment differ widely, they all coincide in predicting that innovation related occupations in developed countries should, even in the less optimistic scenario, double between today and the year 2020.

32. Scherer and Ross (1991) indicate that in a study for the US, the R & D costs to imitator firms of unpatented goods were 50% of the original innovation in 86% of the 127 industries covered. Duplicating costs exceeded 75% in 40% of the industries studied.

33. According to Forrester (1990) the purchase of a US$ 2000-5000 personal computer by a corporate client implies normally additional costs on peripherals, software and maintenance of up to US$ 20000.

34. Expert systems are specialist, information-intensive problem-oriented software. Essentially they are software packages written in a problem-solving way. They include all the information available on a very specific area of knowledge so that managers can seek for 'their advice' when making decisions.

They are the result of 30 years of research on Artificial Intelligence applied to management and are extremely expensive.

35. In 1988 the top four packaged software companies accounted for 36.3% of the world market while the top ten accounted for 56.7%. In 1987, the top four and top ten software vendors accounted for 49.2% and 64.1% of the developed countries' market (Schware, 1989).

36. The 'flexible specialisation' model of industrial organisation associated to the 'Third Italy' and first stated by Piore and Sable (1984) is not unique to this area as can also be found in the Jutland province of Denmark and in Germany's Baden-Wurtemberg (Inzerilli, 1991; Schmitz, 1990). Others, following Marshall, refer to this model as the Marshallian industrial districts (Brusco, 1990; Becattini, 1990). For sympathetic and otherwise reviews of the 'flexible specialisation' model see Amin and Robins (1990), James and Bhalla (1991), Schmitz (1990), and Williams et al (1987).

37. Authors like Sayer (1988) and Williams et al (1987) have argued that the 'Third Italy' evidence is so localised and atypical that it can hardly be used as the basis for any generalisation.

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