Innovation in a Mature Industry:
Evidence from the Textile and Clothing Sector

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1.INTRODUCTION

This work deals with innovation in textile-clothing industry. Usually defined as a declining industry and the next domain of low-wage countries, textile-clothing still remains one of the most intriguing *paradoxes* for scholars of industrial development and technical change.

On the one hand, one can find that the sector shares many of the characteristics often ascribed to *mature industries* (OECD 1988). They are: i) a slowly growing or stagnating output, mainly represented by standardized products; ii) the production of a great deal of value added in the last stages of the manufacturing process ("downstream bias") (see also Pepper Battacharya 1991), where price competition is very strong; iii) the relatively high degree of labour-intensity, coupled with a very low level of directly performed research activities; iv) The intervention of the governments of developed countries supporting mature industries, also because of the highly significant share of the labour
force which is still involved in those sectors.

On the other hand, and in spite of the above-mentioned declining picture, one finds that the textile and clothing industries show some characteristics which are all but typical of a mature sector. As an example, one of the reportedly most impressive cases of productivity growth in the last two decades is found just in textile-clothing. Productivity growth has been remarkably higher than the manufacturing average in the US (MIT Commission 1987; Baily and Chakrabarti 1988), in Germany (Hartmann 1985) and in Italy (Heimler and Milana 1984; Milana 1987). Moreover, contrary to the traditional representation of a sector poorly involved in research, partly publicly-supported research programs have been set-up at the beginning of the '80 in the main industrialized countries (the US, Japan, the EC, Sweden) to ultimately pursue what still today seems to be a futuristic objective - a fully automatic sewing system. Should this plan succeed, the clothing sector will surely be revolutionized, with enormous consequences in developed as well as in developing countries. Furthermore, the sector represents a puzzling case for industrial and international economists. In fact, some industrialized countries - such as Germany, Italy and Japan - still continue to play a major role in international trade in a sector which, in theory, should be dominated by countries whose unique competitive advantage is cheap labour.

In a traditional, or supplier dominated sector - like textile-clothing - "most innovations come from suppliers of equipment and materials" (Pavitt 1984, p.356). Thus, the *use* rather than the *production* of innovations is crucial in these sectors. In addition, it is usually by means of the adoption of new capital goods or systems that innovation enters a traditional industry, like textile-clothing. The latter is, in fact, a poor performer on the ground of product innovation, whereas it has been characterized by significant improvements of the production processes. Thus, in this work, mainly process innovations are analysed. Furthermore, new developments due to the rise of *generic technologies* (i.e. flexible in use), such as microelectronics, new materials, biotechnology are offering new opportunities to the technological upgrading of textiles and clothing.

The work is structured as follows. The technological developments which have taken place in textile are described in chapter 2, taking into account the entire production *filière*, from fibre production to finishing of fabrics. In chapter 3 the efforts to innovate the clothing cycle are outlined. The clothing technological upgrading differs from that occurred in textile, because it is mainly with the advent of microelctronics that the sector starts to significantly change (chapter 3). Chapter 4 draws the main conclusions of this work.

2. INNOVATION IN THE TEXTILE SECTOR

This chapter analyses the main innovations occurred in textiles in the last fifty years.
Two main analytical choices are the guidelines of this chapter.
The first is to examine technical progress as it occurs along the whole textile *filière*. The sector changed significantly, with technology playing a critical - though all but unique - role, despite the extremely low R&D commitment. Borrowing from technological developments in other domains has been vital for textile-clothing. As a consequence, an analysis of innovation in the sector has to take into account the evolutions in surrounding activities, such as chemicals, which provided the textile and clothing sectors with new fibres, new raw materials and even new products (e.g. non-wovens).
The second choice relates to the type of technical change to focus on. On this ground, *embodied* forms of technical change are mainly examined. This seems an appropriate choice, given that investment in innovative machinery (already *incorporating* technical advances) is a relevant - if not unique - source of technological upgrading in *traditional sectors* (for evidence on the Italian case see Quaglia *et al.* 1990). In other words, in these sectors technological innovation mainly concerns the development of new *capital goods*.
In this chapter main innovations in textiles, together with data on investments and patents in spinning and weaving are analysed, in order to reach an empirically based judgement of the innovative effort in the sector.
The whole range of activities important to textile production can be grouped into four broad categories: i) fibre production; ii) spinning, i.e. the process transforming fibres into yarns (the process is not used in the case of silk and of some man-made fibres - such as polyester, nylon, rayon - produced as continuous filament); iii) weaving or knitting, i.e. the phase during which yarn is converted into fabric[1]; iv) finishing, or the process during which the fabric is printed, dyed and undergoes all those transformations which finally reduce it into its definitive form. The production of apparel and fabricated textile products (e.g. home furnishing products), can also be conceived as belonging to textile, even though this phase is properly performed by clothing firms.

[1] This phase is not performed for specific types of textile products, such as non-wovens.

There is nothing new in the task performed in the above-mentioned phases: the situation is exactly the same as many centuries ago, when textiles started to be made in order to satisfy a basic human need. Nevertheless, technical change in textiles - expressed in terms of reduced production time - has been dramatic in the last two centuries. From hand spinning of the XVIIIth century to nowadays *open-end* technique the time required to produce 1 Kg of yarn is almost one hundred times lower (Figure 1).

Textiles, like many other traditional sectors, have hardly ever been the source of autonomous research and the major evolutions in technologies are due to developments occurring in surrounding domains. Indeed, reviewing the innovation process of the textile sector in the last decades, one finds two main sources of innovation: 1) fibres and new raw materials; 2) textile machinery. Moreover, the introduction of new fibres positively influences the adoption of new machinery (Yamazawa 1983), which in turn allows the further use of innovative fibres. A virtuous circle, in which significative *technical externalities* (Antonelli *et al.* 1992) are operating, seems to reinforce itself producing a highly positive impact on textiles.

The two above mentioned trajectories of technological upgrading represent the influence on textiles of two subsequent waves of technological change, i.e. firstly the *chemical wave* of the 50s and, secondly, the *microelectronic wave*, starting with the 70s (Rullani and Zanfei 1988). Nevertheless, the incremental advances occurred in *engineering* - constantly supporting textiles productivity gains - should not be underestimated. In its history, textiles have constantly taken advantage of a process of *technological convergence*. This already happened during the Industrial Revolution[2], but nowadays it is still a main driving force of textile technological upgrading.

2.1 New fibres and materials from the chemical industry

The chemical industry - or better the petrochemical industry as shown in Figure 2 - constantly provides the textile sector with new synthetic fibres[3], a crucial source and spur

[2] "The mechanical achievements of the XIXth century in textile manufacturing were dependent on the great advances in light engineering at a craft level in clock - and watch - making, in lathe work in wood, and in various crafts working with non-ferrous metals" (Usher 1967, as reported in Marchionatti 1989).

[3] According to their physical form, fibres can be categorized in two main groups: continuous filament and staple (UNIDO 1992). When continuous filaments are produced the process of spinning (see infra) is omitted (Pepper and Battacharya 1991).

for technological innovation. Main synthetic (or non-cellulosic) fibres are polyester, polyamide (nylon) and acrylic, which are available both in filament and in staple[4].
The first achievements in developing new fibres date back to the beginning of this century. In 1905 Courtaulds produced in Coventry (UK) the first man-made (cellulose-based) fibre, viscose rayon (Davies 1990). In 1937, Du Pont introduced nylon 66 in the production of stockings, after an eleven-year effort to develop new synthetic fibres (Jewkes *et al.* 1958). Man-made cellulosic fibres are progressively supplanted by synthetic ones.

TABLE 1 ESTIMATED WORLD PRODUCTION OF MAJOR FIBRES
('000 tonnes)

			Man-made	Fibres	
	Cotton	Wool	Synthetic	Cellulosic	TOTAL
1900	3,162	730	-	-	3,893
1940	6,907	1,134	-	1,127	9,173
1950	6,647	1,057	69	1,608	9,381
1960	10,113	1,463	702	2,656	14,934
1970	11,784	1,602	4,814	3,578	21,779
1980	14,228	1,608	10,682	3,554	30,060
1987	17,296	1,612	13,758	2,549	32,215
1989	18,733	1,933	14,717	1,946	37,329

Source: Textile Organon (June 1990) and International Wool Secretariat as reported by Pepper and Battacharya (1991)

Starting from the 50s, both production and consumers acceptance of synthetic fibres has been growing steadily, mainly at the expense of the cotton share (see table above and Figures 3-4). World production shows a sustained growth from 8.9 to 14.7 million tons between 1977 and 1990. Moreover, in 1986 in the US, cotton and other natural fibres represent a minority (35%) of the total fibres consumption[5], while synthetic fibres have a leading 65% share

[4] The whole range of fibres is completed by: i) natural fibres, including: cotton, wool, linen, jute, silk; ii) cellulose-based man-made fibres, including acetates and rayon (UNIDO 1992). Because of the increasing use of blends, the distinction between natural and synthetic fibres is not very rigid, when their applications in clothing are considered.

[5] Consumption relates to all major end-uses: apparel, home furnishing and industrial uses.

(UNIDO 1992). However, the use of blending of natural and synthetic fibres (e.g. cotton and polyester blends) has spread rapidly, with reduced competition between these two broad groups of fibres. Fibre technology today is best mastered by German firms. However, two main groups of world-scale producers can be found: the US (Du Pont, Monsanto), Japan (Toray), Germany (Hoechst) and Italy (Montefibre) in the North and China, Mexico, South Korea (see Enos and Park 1988) and Taiwan in the South. The main achievement reached by means of the introduction of synthetic fibres is the possibility to *control* the characteristics of new fibre *families* (and of an array of mixed fibres) specifically shaping their production on the user's needs. There is also a crucial upgrading in quality (in terms of strength, fineness and uniformity) of the synthetic products, compared to traditional natural ones. Most importantly, the new fibres second and accelerate the improvements which are progressively taking place with the introduction of new textile machinery, mainly allowing significant increases in their speed. There has been a continuous flow of new fibre production during the last years fitting several end-uses, which is still continuing today. For example, the so-called highly oriented and fully oriented yarns (the latter particularly suitable for industrial uses) are currently produced by altering the conventional structure of the fibre; a new polyester yarn (dimensionally stable polyester) is used in tyre cord fabrics (UNIDO 1992). Reportedly, *microfibres*[6] are very promising new fibres, whose main property is their extreme fineness (Assofibre 1992; Davies 1990; Kalogeridis 1992). This is due to the possibility to reach a very low (less than 10 micron[7]) fibre diameter, (see Figure 5), which also makes these fibres extraordinarily light (1,000 metres weigh only 1/10 of gram) (Visciglio 1992). It is worth noting that further reduction of fibre diameter is technically feasible, as far as the mere process of fibre formation is concerned, but it is constrained by the *bottleneck* of the availability of textile machinery which can deal with such thin fibres. On the contrary, new microfibres are fully versatile, being processed both with the most innovative technologies and with more traditional ones. A treatment to reduce polyester weight (by corrosion), obtaining a fibre diameter around 11-12 micron, was already known in 1963, but it required substantial refinements in order to be fruitfully developed on an

[6] Microfibres can be obtained from proper treatment of the main synthetic fibres: polyester, polyamide and acrylic (filaments and staples) (Assofibre 1992).

[7] The thinnest produced fibre has (currently) a 6.5 micron diameter (Assofibre 1992).

industrial scale, and thus it was abandoned for almost a decade (Assofibre 1992). However, during the 70s, the process was reintroduced in Japan and Italy. Japan is, for various reasons, the leading country in developing silk-like filaments, Italy (Montefibre) being the only serious competitor from Western Europe on this ground (Davies 1990). During the 80s, microfibre production spread in the main industrialized countries and was progressively developed until the current level. The main world chemical companies - Teijin, Toray Industries, Mitsubishi and 16 companies in Japan (Davies 1990); Du Pont and Monsanto, in the US; Montefibre, ICI, Akzo, Hoechst, BASF and Rhone Poulenc in Europe - are fiercely competing in microfibre production, developing their own specialties. Contrary to more traditional synthetic fibre production, NICs (except Korea) and LDC are *almost totally out of this business*, though this is all but surprising: microfilament production is expensive (lower machine throughputs) and difficult (frequent filament breakings).

In 1991, the microfibre share of polyester filament reportedly reached around 5% of the total, while experts forecast a considerable increase - up to 50% - in 1995 (Kalogeridis 1992).

The effect induced by fineness in a microfibre-made fabric is quite like the feel (or the *hand*) of silk (Davies 1990). At a first glance it could be surprising that the latest attempt to imitate natural fibres by means of synthetic ones aims at the replication of silk, a highly difficult fibre with a relatively small market share (0.2% of world fibre production in terms of volume). Indeed, the efforts of the main chemical concerns can be better understood if the high value, relative scarcity and fluctuating availability of silk are taken into account.

However, it has been observed that microfibres are not only competing with existing natural fibres, as far as their end-uses are concerned. They are also supposed to fill the gaps left by traditional fibres, which cannot reach the desired combination of properties necessary to the introduction of innovative apparel products. As an example, in a Terital Zero 4 (Enichem-Montefibre) microfibre-made fabric, the density of filaments (above 25,000 per centimeter) allows superior waterproofing performance, with no need of the usual complex finishing procedures for coating (Davies 1990). Moreover, this property is matched with permeability to water vapour, lightness, softness, but also high strength, making this fabric particularly suitable for end-uses ranging from sportswear (skiwear, trekking, jogging), to tents for camping and sleeping-bags (Assofibre 1992).

However, apart from the above-mentioned sports segment of the apparel market, the most important application of microfibres (60% of the total in terms of volume) is the fashion market: blouses, dresses, trousers, skirts, women's suits, blazers and lounge suits (Heindenreich and Ninow 1992).

Furthermore, the chemical industry has provided textiles with totally new processes, like those used to produce the so-called *non-wovens*, a kind of fabric in which the phases of spinning and weaving are completely replaced by chemical and thermal treatments for the cohesion of the fibres.

2.2 New textile machinery from mechanical engineering: a) spinning

A wide range of operations, preceding the actual spinning, is usually labelled as 'spinning phase'. Nonetheless, the spinning stage covers more than half of the yarn production cost and the bulk of the innovative effort has been devoted to this phase.

The process starts with the opening of the bales of fibre (e.g. of cotton) and, if necessary, with the blending of different kinds of fibres. This is followed by carding, drawing, combing and roving. These stages are performed in order to clean and make the fibres parallel before the actual spinning phase starts. The use of specific synthetic fibres allows for the simplification of the whole process, because some of the above-mentioned pre-spinning phases are not required[8].

Before analysing in depth the evolutions in spinning, it is worth recalling that significant improvements took place in previous stages of the process as well. As an example, automation is used in bobbin doffing, in bale opening and in piecing. It is also applied to improve the flow of products between different operations, to substitute manual transfer of materials and semi-finished products, with an increase of productivity levels. In addition, the use of information technology in production control significantly helps management to upgrade the quality of products, by means of a constant check of the process, and allows a better use of raw material (see OECD 1988).

The most traditional system in spinning and also the most widely represented into the world installed production capacity (see table 2) is currently the so-called *ring spinning*, centred on the movement of the spindle on a ring circuit. The main characteristics of this spinning

[8] For example, synthetic fibres contain less trash than natural ones (which in turn means that carding can be more rapid), while the length of fibres can be pre-determined during their production process.

method are its relatively high versatility (in terms of the various counts and qualities of yarns which can be spun) combined with a rather low energy requirement.

The system was unchallenged until the post-war period, when in 1947 in Czechoslovakia an innovative procedure (i.e.*open-end spinning*) was invented, though its introduction on an industrial scale dates back to the 60s. The biggest effort is devoted to increase the *speed* of yarn production. On this ground, the availability of synthetic fibres was crucial.

Open-end spinning is usually referred to as a revolutionary innovation for textiles. Indeed, it represents a true *breakthrough* in the way the production process is designed and realized, as it makes possible highly significant gains in terms of productivity rate. On the one hand, some pre-spinning phases - such as drawing and winding - become redundant and can consequently be eliminated. On the other hand, in actual spinning, the ring and the spindle are totally *removed* and the fibres are spun by means of an air suction. By measuring yarn production rate in terms of revolutions per minute (rpm), the productivity gain associated with the introduction of open-end spinning amounts to the jump from 10,000-14,000 rpm in traditional ring spinning to 40,000-50,000 rpm with open-end technique (Pepper and Battacharya 1991). The above-mentioned comparison is, of course, only one part of the whole story of the *technological competition* between them. As it has been observed in classical studies (Rosenberg 1976), the introduction of an innovation spurs a stream of incremental improvements in the pre-existing technology, in such a way that the two competing technologies coexist for a certain period. The incremental refinement of the older production process can seriously slow its replacement with a superior new technology, whose diffusion rate is correspondingly delayed. The most significant improvements in ring spinning are: a substantial increase in speed (up to 18,000 rpm); automated repair of the broken yarn ends; automated clearing. The competition between the two spinning technologies has taken place on a number of different grounds: labour and energy requirements, capital cost, yarn count, spinning speed.

At the beginning, this led to a sort of specialization, with open-end spinning (still to be perfected) more suited for coarser yarns, showing a lower breakage rate, and ring spinning still competitive for finer high count yarns. As figure 6 shows, in the early 80s a definite range of high yarn counts (30 counts and above) can still be found where the *older* technology (ring spinning) scores comparatively *better* than the newer one (open-end spinning) in terms of production cost. However, it is possible to assume that - with the continuous improvements in the new technology - the shift from open-end spinning back to ring spinning will be economically efficient only for very fine yarns, while over the long term the new technology will eventually completely (i.e. for all counts) replace of the older one. As a matter of fact, at the end of the 80s, the cross-over point between open-end and ring spinning had reportedly shifted at around 40 counts, when open-end operated with clean fibre (Pepper and Battacharya 1991). Moreover, at the end of the 80s, the speed of the open-end rotor reached an order of magnitude of around 90,000 rpm. This continuous improvement in speed is crucial in order to widen the range of yarns which can be spun with the new technology to include the finest yarns. Indeed, being production targets in spinning fixed in terms of weight of the yarn, a longer length of finest yarns has to be spun for any given weight, compared to coarser yarns. Then, to effectively compete with the traditional technology on higher yarn counts, open-end spinning has to secure a higher production rate (i.e. higher speed) which can compensate the higher capital and energy cost, but also a higher rate of breakages. In addition, the outcome of the two processes is different: ring spun yarns are more solid, while open-end rotors produce a more uniform yarn, which meets the requirement of the weaving phase.

As a result, the superiority of one technology over the other depends on "a combination of economic and technical factors such as: i) the desired range of yarn counts; ii) the relative cost of labour; iii) the availability of skills for operation, maintenance, and production management; iv) the type of raw material, its quality and price" (Pepper and Battacharya 1991, pp.35-36). Furthermore, the above-mentioned combination of factors is significantly altered by *adoption externalities* (Antonelli *et al.* 1992). While *each firm* at any level of the textile *filière* adopts the new technology based on its own decisions (i.e. based on profit maximizing criteria), it is at the *aggregate* level that the interdependence between seemingly separate investment behaviors clearly emerges. Indeed, given that open-end rotors show a superior productivity when they spin synthetic fibres (or their blends), it is straightforward that a higher diffusion of those fibres makes it easier to adopt open-end rotors. Of course, this is a two-sided process: an increased demand for synthetic fibres -due to innovative spinning techniques - provides a further spur to the expansion of their production.

Moreover, for the whole adoption process to work effectively, *network externalities* are also very important (Antonelli *et al.* 1992). In this sense, several factors are crucial: the rapid flow of information (ranging from new raw materials, to new technologies, new suppliers, new potential markets) among the firms in the network, the upgrading of local labour market, the development of the supply of new complementary inputs (e.g. maintenance), with corresponding decline in the costs of these services. The introduction of new materials and new processes substantially changes the mode of production, demanding a skilled (usually male) workforce, as opposed to traditionally low skilled (usually female) labour.

Technological competition does not only stimulate the upgrading of older techniques, but it also leads to constant renovation of the newer one. In open-end spinning further developments of the original idea have recently taken place, with the introduction of air jet and friction spinning methods[9]. As usual, both present some drawbacks: the former is particularly appropriate for longer fibres, while it is less effective with shorter ones; the latter, theoretically of a high versatility, is currently applicable mainly for coarse yarns. Technology competition is then complicated by the emergence of these two new methods. However, the overlapping of different technological options is limited to given range of counts. As shown in figure 7, for example, competition seems to take place among ring spinning and air-jet spinning in medium to finer yarns.

Although important developments have characterized spinning technology in the last decades, *traditional* ring spinning still represents the *dominant* technique in the world spinning capacity. Figures on world[10] *installed* capacity in 1991 show that more than 169 million spindles were installed as opposed to around 8 million open-end rotors, which amounts to a rotors diffusion rate of around 18%[11] (see table 2).

[9] In air jet spinning, fibres are reduced to yarn crossing an area where two nozzles create a vortex pushing air from opposite directions. In friction spinning, yarn is formed by collecting fibres on a moving perforated surface (drum).

[10] The world total does not cover shipments by the People's Republic of China (ITMF 1993).

[11] The rough estimate of diffusion rate has been obtained by applying a productivity factor of 4.5 for open-end rotors in order to express their production capacity in ring spinning equivalents. I am grateful to Mr P.Munkholt (ITMF Zurich) for his valuable suggestions.

TABLE 2 COTTON-SYSTEM SPINNING WORLD CAPACITY

million units			
	1981	1991	1981/91 percentage change
Ring spindles	150	169	12.7
OE rotors	4	8	100
OE diffusion (%)	10	17.6	

Source: based on Strolz (1985) and ITMF (1993)

Nonetheless, as shown in table 2, from 1981 to 1991 the absolute number of rotors in total installed capacity has doubled, with a corresponding growth of their diffusion rate from 10% in 1981 to around 18% in 1991. At a country level, it is possible to find very different diffusion rates, ranging from levels above 60% in Hong Kong, Sweden and the former USSR to less than 5% in Egypt, India and - surprisingly - Korea. By now, in countries such as the US, Germany and France the highest share of 1992 investments is mainly constituted by open-end rotors (ITMF 1993; Antonelli *et al.* 1992). Furthermore, from 1985 to 1991 a substantial expansion of the open-end rotor share of total installed capacity was experienced in several countries: in France and Turkey[12] the share increased fivefold, in the US threefold, in Taiwan and Austria twofold. As a consequence, although ring spinning still dominates in the *installed stock* of machinery, it is also possible to observe during the 80s a growing acceptance of the new open-end technology, as reflected by the recent upward trend of *investment flows* .

The main innovators in spinning technology emerge from the analysis of the patent applications at the European Patent Office (EPO) in Munich (Germany), during the period 1978-1991. Applications from as many as 15 countries can be found, with the innovative activity strongly concentrated in only two of them, Germany and Switzerland, which together account for almost 60% of total applications in spinning, followed by Italy and Japan (see table 3). The record of annual application flows shows an increasing number of applications (though a more restricted number of applicants) in the period 1988-1990.

[12] The strong commitment of Turkey in upgrading the technological level of its spinning capacity is worth noting: in 1992, the country scored third in world ranking of main investors in open-end rotors, with 31,451 shipments, following the US (96,903) and the former USSR (80,888) (ITMF 1993).

TABLE 3 PATENT APPLICATIONS AT EPO: SPINNING
(technological class D 01 H)

	80	81	82	83	84	85	86	87	88	89	90	91	Total
FR	2	2	3	2	2	4	3	2	7	4	7	5	43
IT	8	6	2	5	2	1	4	10	14	15	13	21	101
DE	5	5	8	5	6	17	14	5	38	56	58	32	250
GB	2	5	3	1	6	10	7	3	7	3	3	1	51
JP	2	1	9	7	4	3	4	7	10	15	20	5	89
US	7	2	1	2	1	4	1	1	6	4	1	0	33
CH	9	8	12	10	11	8	13	9	24	34	45	44	233
Other	1	1	2	2	2	0	1	2	4	1	4	0	20
TOTAL	36	30	40	34	34	47	47	39	110	132	151	108	808

Legend: FR=France; IT=Italy; DE=Germany; GB=Great Britain; JP=Japan; US=United States; CH=Switzerland
Source: Cespri-Bocconi Patent Database

This changing investment behaviour has, in turn, relevant implications for the textile *filière* as a whole. Indeed, the fibres which are best suited to open-end rotors had different characteristics (firstly in terms of superior strength, then in terms of fineness) than the one used in ring spinning (whose main property is length and uniformity). Stated that a period ranging from 5 to 7 years is requested to change the quality of cotton crops to grow, the suppliers of cotton should be aware of the evolutions of spinning machinery investments (Strolz 1985).

2.3 New textile machinery from mechanical engineering: b) weaving

The aim of weaving has not changed from time immemorial: fabric is obtained by interlacing two series of yarns at right angles (lengthwise=warp; crosswise=weft).

After John Kay's *fly shuttle* loom (1733)[13], Edmund Cartwright's power driven loom (patented in 1786) and Jacquard's (1803) perforated card programmable loom - the history

[13] The *fly shuttle* loom, though still a hand loom, is depicted as "a strategically important innovation" inasmuch as it establishes "the general features of a picking motion that might be applied to a power loom" (Usher 1959, p.286).

of weaving technology witnessed another period of important developments toward the end of the XIXth century. By that time, the automatic bobbin change loom was introduced by Northrop in the US (1894). More recently, in the early 50s, one finds the next quantum jump in weaving technology, when Sulzer (Switzerland) introduced the first *shuttle-less* loom. The history of this innovation is of some interest, inasmuch as it shows a rather conservative attitude of the sector towards the introduction of innovations. Indeed, the first studies on the possibility of modifying the structure of the traditional loom were undertaken by a German individual inventor, Rudolf Rossman, as early as the 20s. No textile machinery manufacturer was interested in the development of Rossman principles, and his patents were taken over by a Swiss consortium in 1931. The development was assigned to Sulzer Brothers, a distinguished Swiss engineering firm but without any previous experience in textile machinery. Sulzer actually *entered* the textile machinery business with this development project. In 1945 the first licence for a new loom was granted by Sulzer to an American firm, while in 1950 the first plant was equipped with the new looms. It has been sharply observed that: "the Sulzer loom is a case where an original idea was conceived of by an individual inventor, where the firms in the textile machinery industry took little interest in the invention and where the development, which proved to be prolonged, was undertaken by an enterprising firm outside the industry" (Jewkes *et al.* 1958; p.304).

A brief illustration of weaving productivity gains in the last two centuries is offered in Figure 1: it shows that nowadays it takes 40 minutes to weave 100 square metres of fabric on a jet loom as opposed to as many as 200 hours on a hand loom of the XVIIIth century.

As with the introduction of open-end rotors in spinning, the launch of shuttle-less loom revolutionized the very concept of weaving: the shuttle (after intermediate passages) has eventually been removed and alternative weaving principles have been introduced: projectile loom, rapier, jet looms (air jet and water jet), until the latest and fastest - though still to be perfected - multiphase loom[14]. What all these new techniques roughly do is to improve the traditional weft insertion system, by substituting the traditional shuttle with other ways of carrying the weft along the cloth width. Two main gains can be realised with these innovative looms: 1) speed (measured in terms of weft inserted per minute); 2) loom width.

[14] The first jet machines were developed by Investa (Czechoslovakia) in the 60s; in the same country the first multiphase technology was also developed (MIT Commission 1987).

Speed has dramatically grown. At the end of the 80s the whole family of shuttle-less looms recorded productivity gains over the traditional automatic shuttle loom which reached up to 300 metres of weft inserted per minute. Speed ranged from 3 times faster for rapier looms (up to 900 metres) to almost 5 times faster for jet looms (up to 1,400 metres) (Pepper and Battacharya 1991).

Width has also significantly been increased, starting from the mid 70's. As a result, it has been possible to weave steadily increasing cloth widths, depending on the specific adopted technique: 280 cm with rapier loom, 400 cm with air jet method, up to 540 cm in projectile (Pepper and Battacharya 1991; Ray 1984).

Furthermore, compared to the previous shuttle technology, new looms attain a higher degree of reliability in the final product (a lower defect rate), though workers can control a higher number of looms at the same time (Ray 1984). The gain in terms of noise reduction obtained by shuttle-less looms suppression should also not be underrated.

A recent estimate sets between 30% and 50% the reduction in fabric production costs when shuttle-less - rather than traditional automatic looms - are adopted (Antonelli *et al.* 1992).

Of course, some shortcomings still exist also for these innovative weaving technologies. Firstly, they are not as *versatile* as the older shuttle loom, in terms of the number of colours which can be woven at the same time. Secondly, they generally require stronger yarns - due to the higher weaving speed that are able to achieve. In addition, water jet looms grant higher productivity when hydrophobic yarns are used. It is worth noting that the latter technique scores rather badly when taking into account the cleaning costs of highly polluted water before recycling. Thirdly, plant size and the number of loom's should reach a minimum threshold in order to make the investment economically effective. This is the case with jet looms, although rapier and projectile are less demanding techniques on this ground. Finally, energy consumption is usually higher if compared to traditional shuttle looms and tends to increase with speed.

In weaving - as in spinning - the *dominant* technology is still the *traditional* one. In 1991, the world installed capacity for cotton-system weaving amounted to 2.1 million shuttle looms and 642,000 shuttle-less looms, roughly setting the shuttle-less looms diffusion rate[15] at around 23% of the total (see table 4).

TABLE 4 COTTON-SYSTEM WEAVING WORLD CAPACITY

'000 units			
	1981	1991	1981/91 percentage change
Shuttle looms	1,820	2,128	16.9
Shuttle-less (SL)	261	642	146
SL diffusion (%)	12.5	23.1	

Source: based on Strolz (1985) and ITMF (1993)

However, a comparison with the 1981 figures shows that the number of shuttle-less looms increased by almost 2.5 times, by far outranging the modest shuttle looms increment. In turn, this caused the doubling of shuttle-less looms diffusion in a decade. In 1992, the almost 59,000 shuttle-less shipments were mainly directed to Asia (62%) and Eastern Europe (20%), followed by the EC (7%) and North America (5%) (fig.8). The distribution of shipments strongly differs among various world regions: jet looms represent almost 70% of Asian investment as opposed to a share of around 90% for rapier and projectile technology in Europe[16] (Figure 9). China was the largest individual market in 1992 - purchasing 11,375 shuttle-less looms (+291% respect to 1991) - followed by former USSR, Korea, Japan and Taiwan.

A breakdown by proponent country of patent applications at EPO in 1982-1991 is presented in table 5. Weaving innovations come from a larger group of countries than for spinning, with 19 applicant countries in weaving as opposed to 15 in spinning. Nonetheless, also in weaving a restricted group (Switzerland, Japan, Belgium, Germany and Italy) represents quite a high proportion (more than two thirds) of the total number of patent applications.

[15] The diffusion rate is calculated in this case as the ratio of shuttle-less to shuttle looms. Contrary to what has been possible for spinning, it is not feasible to make a comparison which takes into account the superior productivity of the *family* of shuttle-less looms, which would require an exhaustive outline of the *composition* of the installed capacity for shuttle-less looms (see Strolz 1985).

[16] It is worth mentioning that these figures refer to shipments and consequently give only a partial view of investment patterns: in fact, looms produced and domestically adopted in the main producing countries are not taken into account.

TABLE 5 PATENT APPLICATIONS AT EPO: WOWEN FABRICS; METHODS OF WEAVING; LOOMS (technological class D 03 D)

	82	83	84	85	86	87	88	89	90	91	Total
FR	2	4	11	4	6	4	8	4	13	2	58
IT	5	5	9	6	7	4	10	10	11	10	77
DE	6	6	7	9	6	15	13	15	14	10	101
GB	4	3	2	1	0	0	1	3	4	1	19
JP	12	23	8	9	17	10	17	14	11	20	141
US	1	6	8	1	3	5	2	6	4	1	37
CH	14	23	26	21	14	17	15	18	23	10	181
BE	4	2	5	6	11	21	24	15	16	10	114
Other	1	13	6	6	4	7	13	9	16	4	79
TOTAL	49	85	82	63	68	83	103	94	112	68	807

Legend: FR=France; IT=Italy; DE=Germany; GB=Great Britain; JP=Japan; US=United States; CH=Switzerland; BE=Belgium
Source: Cespri-Bocconi Patent Database

The leading proponent is Switzerland - the country where shuttle-less loom was first introduced by Sulzer - accounting for one fifth of the patent applications from 1982 to 1991. Japan (16%) follows, then Belgium (13%) and Germany (11%). Main world suppliers of weaving technology (apart from the above-mentioned Sulzer) are: Ruti and Sauer in Switzerland, Nissan, Toyoda and Tsudakoma in Japan, Picanol in Belgium, Dornier in Germany, Somet and Vamatex in Italy (UNIDO 1990). From 1986 to 1990, the number of total patent applications increased (except for 1989), whereas in 1991 a drop took place.
It is worth noting that *knitting* can sometimes be considered as competing with weaving techniques. Instead of using two ends of yarns (weft and warp), only one is used in knitting - either weft or warp. In warp knitting, for example, the yarn zigzags along the length of the cloth - only covering the horizontal distance between one needle and the other, instead of travelling along the whole cloth width. The correspondent gain in terms of productivity is remarkable: warp knitting fabric production rates can be up to 30 times higher than weaving[17]. In weft knitting, fabric production rates can exceed those in weaving by a factor

[17] However, warp knitting presents some limitations in the type of yarn to be processed.

ranging from 3 to 5 (Pepper and Battacharya 1991). Moreover, one of the first recorded applications of CAD in the textile *filière* took place in knitting in the early 70s. Patterns to be reproduced are scanned and stored in a central processing unit, which in turn guides needles and properly selects the yarns. The result is to dramatically reduce the time from design to the production of a first sample: from two weeks to two hours (Finnie 1990).

2.4 New textile machinery from mechanical engineering: c) finishing

Finishing - also including colouring and printing - is one of the highest value added production phases in the whole textile cycle, during which the fabric becomes a finished product. This phase is based on a mix of semi-artisanal operations performed by highly skilled workers, also supported by very sophisticated treatments, which gives as a result the effect usually labelled by textile experts as the *hand* of the cloth. This term indicates a blend of properties such as softness, color uniformity and definition, wrinkle and shrink resistance, shape retention. All these characteristics give a concrete meaning to the otherwise indefinite concept of *quality*. As a result, the price of a finished fabric can be from 100% to 200% higher than that of an unfinished one (Pepper and Battacharya 1991). The relative complexity of the operations undertaken in finishing (and, consequently, the relevance of accumulated skills) and the possibility to realize significant economies of scale in the country of origin contribute to explain the difficulty in moving this production stage in developing countries. Technical progress in finishing benefited from the technological convergence of advances in several fields, ranging from chemistry to mechanical engineering, to printing and even optics (photometry).

The first achieved improvements relate to the reduction of water and energy consumption. Automation has also been applied in Japan to test the results of finishing treatments. The Kawabata Fabric Hand evaluation system is used to appraise the quality of cloths on a more objective basis: instrument readings of fabric replaces the traditional "feel" analysis (Krol 1985).

A main development in printing is screen printing, allowing a superior color definition and a higher speed. This development covered more than a half of the textile printing market by the beginning of the 80s. However, it is with the application of *computers* that printing finds a crucial source of productivity gains and quality upgrading, as will be discussed more widely in section 2.6.

Technical progress in dyeing was induced by the introduction of synthetic fibre. Indeed, the hydrophobic character of polyester demanded new dyeing techniques, which could work without water. This led to the introduction of *dispersion dyes*, to be fixed on polyester under high pressure and temperature. Machines working above atmospheric pressure are then required. Another important achievement derives from the adoption of *computerized "color kitchen"*, which allows a more reliable color definition and an easier and more precise color reproduction, by means of the possibility to store specific color recipes.

2.5 Impact of technological change in textiles: growing capital intensity

The intense innovative activity reviewed above has increased the *capital intensity* of the textile industry. The rationale behind the introduction of innovations is usually[18] to respond to growing competition from low-wage countries. In 1991, in industrialized countries, the labour component of manufacturing costs after a substantial reconstructing was no less than 25% in spinning and even higher in weaving (38% in Germany; 36% in the US)[19].

Thus, innovations introduced in textile typically aim to increase capital productivity and tend to be labour-substituting. Recent estimates (Strolz 1985) find the growth of capital intensity in various operations to be as follows: i) a fivefold increase between a mill equipped with ring spinning machinery of 1950 vintage to that of 1981; ii) a more than threefold increase in rotor (open-end) spinning in a shorter period (1971-1983), and; iii) a three and a half fold increase for a shuttle-less loom installation of 1982 compared to a fly-shuttle loom of 1960. Strolz (1985) also finds very high capital input levels in the German textile sector in comparison to industries which are usually highly capital-intensive, such as petrochemicals. This trend has probably represented a significant barrier, which delays the modernising effort of developing countries in their textile sector, especially in a context of growing financial difficulties linked to the explosion of the debt crisis in mid 80s.

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[18] Some innovations have also a *technological rationale*: i.e. it is the connection of some production phases with previous or subsequent innovations in the production *filière*, which leads to technological upgrading (an example is the case of dyestuffs innovation to meet the technical characteristics of polyester diffusion).

[19] Percentages refer to labour weight in manufacturing cost per kg of yarn in spinning and per yard of fabric in weaving (ITMF 1991).

However, this trend may not continue in the future, when a growing share of microelectronic equipped machinery and devices (with falling prices) will presumably enter textile mills. Finally, it is worth noting that the intense development of new textile machinery in the last decades significantly challenges the traditional (and well-established) investment behavior prevailing in this sector. Indeed, the unprecedented rate of innovation in the last years (see Figure 10) produces a more rapid obsolescence of previous models, presumably inducing a delay in new machine purchases, because of the expectation of the launch of a newer, better model. As an example, in air-jet weaving no less than four generations of looms appeared in a eight-year period, something which never occurred before in textile (Finnie 1990). In this way, the sector experiences a well-known phenomenon in literature (Rosenberg 1982, p.114; Schumpeter 1975, p.98) - namely, *technological expectations* leading to postponed investments - which more typically characterizes industries with a higher technological profile.

2.6 The influence of the microelectronic wave on textiles

The recent history of the technological development in textiles is characterized by the first introduction of new machines incorporating microelectronic devices. This process has already been sketched in the case of finishing, but it has also started to spread to many other operations in the textile *filière*.

There are three main fields of application of microelectronics in textiles: i) warehouse operations automation; ii) process control (e.g. electronic-based inspection systems, to improve the quality of processed cloths); iii) adoption in specific production phases, such as CAD applications in printing. Microelectronic innovations usually require a new definition of the whole production process, especially at the organizational level, in order to be fully effective.

A first step towards microelectronics has been the automation of parts of the production process, mainly in warehousing and materials handling. The main aim of this kind of automated systems was to reduce labour requirements. In fact, the cost of labour to simply remove materials is estimated at around 20%-30% of the total manufacturing cost in textiles (Textilia Europe 1992). The scope of materials transfer automation is to give full value to the use of innovative machinery incorporating automated devices, extending automation also to *surrounding* phases, such as machine supply and clearing. In this case, a central computer guides the robot, which is able to perform tasks with different degrees of difficulty, ranging from yarn storage to automatic doffing in spinning, to cone loading and unloading (in some cases, after winding, unloading can be followed by cones storing in boxes), to automatic pressing for bailing and to partial automation of assembly. In many of these cases, the robot is immobile and its potential is partially limited to linking of different production *modules*. A robotized warehouse was supplied by COMAU to Benetton as early as 1985 (Rullani and Zanfei 1988).

In process monitoring one finds a number of potentially useful applications of microelectronics in textiles. They can be roughly considered as serving two broad tasks: i) *detecting and repairing* defects and errors occurring in the production flow; ii) *preventing* defects altogether.

The likely advantages offered by a continuous control of production flows should be appreciated in the current context of increasing production speed, from innovations in spinning and weaving. Thus, a real time defect detection system becomes a crucial feature of an innovative machinery, in order to avoid downgrading an entire production lot, with correspondent losses. The system has to be able to find defects and to automatically modify the machine settings in order to remove faults or, in case this is not achievable, stop production flow. In 1987, expert systems for the textile industry were first proposed at ITMA machinery exposition in Paris. An expert system stores the knowledge and roughly replicates the reasoning capabilities of experts, engineers and technicians (based on a "if ... then" scheme). Such a system is centred on the simple assumption that the knowledge incorporated in skilled personnel is too important to be lost when people leave the firm for various reasons, such as retirement. Expert systems are already in use in many other sectors, such as automobiles, airlines management and banking. In textiles, their setting-up usually requires the cooperation of the textile machinery builder and a firm working in the field of artificial intelligence, which is in charge of the system shell building. Information technology concepts and standard statistical inference techniques are indispensable in building these systems. The German weaving equipment firm Dornier produced, by the mid 80s, a system tailored to the needs of a client, in cooperation with the Institute of Textile Technology (US). This expert system identifies the causes of weaving errors and suggests possible remedies

(Demers 1989). Other machinery suppliers have recently proposed expert systems: the Belgian firm Picanol, using Barco's Sycotex monitoring shell, devised several systems to be applied to its weaving machines. One of them is installed on rapier weaving machines, where a host computer stores all the relevant information regarding filling stops (filling break position, package number, etc.) in case they occur during the production flow. When errors overcome a certain threshold, the system uses data previously collected to provide technicians with a diagnosis on the most likely error source. Further developments obtained by Picanol, allow the expert system Realtex PAT to execute corrective actions on air-jet looms without human interaction. The high level of sophistication of the system also allows the detection of poorly performing machines - something less than a real error and closer to automated *fine tuning* of the machines (Demers 1989; also Textilia Europe 1992).

A further step is to shift the focus from detecting and repairing defects when they occur, to *preventing* them in the first place. To do this, statistical process control schemes can be adopted, which mainly monitor two variables: material inputs and process conditions. The trade-off between quality and cost can be avoided in this way: higher quality *and* lower costs can be achieved just because a continuous process control system reduces verification and failure costs.

However, the diffusion rate of these systems is still low. It has been estimated that - apart from the 50% of the computers used by the US textile industry merely to summarise and calculate data - slightly more than 25% records *what* has happened, around 15% also identifies *why* it happened, while less than 3% are employed in determining what *will happen* (Finnie 1990).

Printing is one of the most interesting fields of microelectronics (CAD) application, when specific phases of the textile cycle are considered. Two broad improvements are possible to realize with the computers: i) to simplify the sequential process of design prior to printing; ii) to conduct these operations more efficiently.

There are different techniques for cloth printing: rotary screen printing is the most widely diffused (65% of the total printing market in 1987, according to Pepper and Battacharya 1991), followed by flat bed screen printing (15%). The concept which inspires the various printing techniques is, however, roughly the same, as it is based on the following *sequence*: design; film production; photoengraving of printing medium (either cylindres in rotary technique or printing plates in flat bed one); cloth printing.

There is evidence of the first uses of microelctronics in textile printing as early as the first half of the 70s.

As an example, in 1974, Miroglio Tessile SpA - one of the leading Italian textile firms - introduced an electronic control system in knitting, specifically tailored to its needs by the Israeli firm Scitex. The latter belonged to the printing sector although, by that time, had started to diversify its business in textiles. The system allowed the use of a graphic table in design, the reproduction of the pattern on a colour monitor and the processing of all the necessary information in order to reproduce the design on a knitted fabric. In the second half of the 70s, another system was devised by Scitex for Miroglio Tessile, in order to produce films for rotary and flat bed screen printing. The success of Scitex systems in the 70s, made the Israeli firm a *specialized supplier* of microelectronic-based design systems for several Italian textile firms.

The traditional sequence in the printing cycle started to be seriously challenged during the 80s. The printing process can be simplified by eliminating the manual production of films, by means of CAD. In some cases, it is also possible to engrave patterns (by means of laser) directly onto cylindres used in rotary printing. The advantages of this simplified process are not only in the shorter time elapsing from design conception to film production, but also in the more reliable realization of the original design: departures from the latter are always possible when different designers are involved in the design phase and in film production. This reorganization of the printing process implies labour displacement: the designers working in film production are no longer performing their traditional job. It is worth noting that, in Miroglio experience, the designers did not leave the firm, because they were preferred to workers trained in information technology, due to the specific skills accumulated in their previous experience in textiles. This allowed them to learn faster than computer experts how to work with CAD printing systems.

According to experts in the sector, around 50% of printing in the Italian textile sector is currently based on computer-based design systems.

Moreover, a number of operations are performed more efficiently. As an example, trials with final customers on different colors and cloth patterns can be made on computer screen instead of producing a number of (highly costly) prototypes. As a consequence, it is possible to only produce the designs chosen by the customer, with significant savings. However, this opportunity is not fully exploited because in textiles the fabric *hand* is still an enormously important aspect in negotiations with clients: textile culture is perhaps too traditional for the advent of computer pattern books. In addition, further developments are required in order to reduce the discrepancy between the fabric colour displayed on the computer screen and the colours achievable in actual printing. The technological frontier in printing is represented by systems which can perform the whole cycle up to cloth printing, by means of appropriate peripherals. In the opinion of the experts this possibility is still very far away.

Microelectronics also seriously helps designers in their creative efforts, allowing the production of archives of images, to be reproduced on fabrics. A sophisticated *development* work has been carried out at Ratti - another outstanding Italian firm mainly working in the silk business. The firm has recently conceived and built a system to store more than 150,000 designs realized from the 40s up to now. It includes a vision system which reads images and saves them on high capacity videodisks. The crucial feature is that the database can be fully distributed in the internal computer network, so that the images can be rapidly retrieved from any workstation connected with the central unit. A sophisticated retrieval scheme (based on a grid of parametres) has also been realized in order to minimize the time involved to search for a desired subject. It is straightforward that designers' productivity can be significantly improved, while the firm's *culture* can be turned into a real source of value added. Finally, the database itself is commercialized by Ratti, which has conceived it from the outset in the most flexible form, so that it could be proposed to a wide range of users, not necessarily belonging to the textile sector.

3. INNOVATION IN CLOTHING

The history of technical change in clothing is different from that in textiles. In fact, the sector did not benefit from technological advances comparable to those occurring in textiles, at least until the 70s, when microelectronics started to be used in clothing.

This is not surprising, given the different nature of the two sectors. Capital intensity in clothing is indeed several times lower than in textiles. As a consequence, the link with a machinery supplying engineering sector in the form of the virtuous user/producer interactions characterizing textiles is also weaker, if existing at all. In this way, a crucial source of technological upgrading for a mature sector - i.e. a sector producing innovative capital goods (Rosenberg 1976) - is denied. The extent of the benefits coming from advances in synthetic fibre production is also limited in scope in clothing, because the production process is grossly unaffected and it is not comparable to the tangible productivity gains recorded in textiles. The tasks to be performed in clothing are actually very difficult to be automated - though they seem very simple in principle, roughly amounting to cutting the material and to sewing.

Until the 70s, the clothing sector in the industrialized countries was in a contradictory situation: on the one hand, there were real difficulties in achieving significant improvements in the production process with the available technologies; on the other hand, the stimulus to labour-substituting automation was even stronger than in textiles, as labour was a sizable component of manufacturing costs, or around 35% of the total in the US at the beginning of the 80s (as opposed to 7% in an Asian NIC) (Hoffman 1985a).

The first technological wave that seriously involved clothing was microelectronics, representing a real *revolution* for a sector where, technical change was more or less unknown until computers advent (OECD 1988).

Moreover, technology developments are only one part of the whole story of innovation in clothing.

A big inducement to innovate in clothing in the industrialized countries was the changing context of international trade, starting from the 60s. In fact, by that time a strong productive capacity was established by that time in developing countries - such as Korea or Taiwan (see Amsden 1989; Hoffman 1985a; for the experience in the footwear sector, also see Donaghu Barff 1990). Clothing is a well suited sector for the take-off of an endogenous industrialization. There are in practice no entry barriers even for very small units (as far as mere manufacturing is concerned[20]) and it is possible to achieve commercial success by using cheap labour as a competitive tool.

As a consequence, the industrialized countries moved from a position of self-sufficiency in the 60s, to growing trade deficits in clothing, reaching around 12 billion dollars in 1980 and more than 40 billion dollars in 1989, for the EC, the US and Japan combined (GATT 1990). The big competitive threat coming from developing countries was countered by the industrialized countries in several ways.

Firstly, there was an increasing recourse to *protectionism*: import restrictions were applied by developed countries, starting with the 1962 multilateral trade agreement (Long-Term Agreement), followed by Multi Fibre Agreement (MFA) negotiations since 1973.

Secondly, starting from late 70s, there was a growing commitment to a *product diversification* strategy, to increase the unit value added of the products supplied by the clothing sector of the developed countries, in order to reduce competitive pressures from low wage areas.

Thirdly, a growing effort was devoted to *reducing costs* (mainly labour cost) through labour-saving mechanization and automation.

The following sections analyse in-depth the technological developments in clothing, mainly due to the applications of microelectronics.

3.1 Computers in the clothing industry: pre-assembly phases: a) design

The first record of the use of computers in clothing dates back to 1967, when Compugraphics International (US) introduced, in its Dutch office, a computer aided system in pattern grading of British Rail's refreshment room overalls (Disher 1986). However, after this pioneering attempt, it is only towards the end of the 70s that computer aided systems started to spread in the clothing industry.

Two main tasks can be performed by means of a CAD system: i) pattern grading; ii) pattern marking (laying out the patterns as a guide for cutting). It is worth noting, however, that a crucial step is made when data on garment specifications are digitized. This provides the necessary information for potential further automation in later production phases, such as

[20] It is worth noting that, on the contrary, significant barriers *do exist* in clothing, in the commercialization of manufactured goods.

cutting and, in theory, assembly. There are many examples of the continuous development of grading systems in recent years (Disher 1991). An example is the pattern design system (PDS). This is a device to modify patterns until the proper shape is obtained: parts can be enlarged on the screen, designed with seams and darts, split and then recombined in different ways. Several parts can be retrieved on the screen at the same time, in order to have them fitted with each other. A *real* effect can be approached on the computer monitor, even with allowances for fullness where needed.

Furthermore, a fully automated pattern generation system (PGS) has been developed. Introduced in the US in 1986 and then perfected in Germany, this device is able to automatically develop size grading, based on a sophisticated software combining standard body measurements and the pattern rules of skilled tailors. This use of tailors' experience makes the system quite close to an artificial intelligence or expert system, as defined in 2.6. Other programs allow to process a more complete set of data on the components of a finished garment. As an example, the so-called Style File provides precious technical information when a new product is studied, allowing a sound assessment of its production cost. Indeed, it provides estimates of fabrics and even of linings required, based on the measurement of pattern perimeter outlines. It can also evaluate the minutes required for each assembly phase, taking into account the highly time-consuming positioning of garment parts under needles (approximately 70% to 80% of total sewing time). Finally, the program can be completed by standard components library, including drafts of pockets, collars and the like.

It is not easy for designers - who worked many years in a totally different manner - to get used to the new technology. This does not necessarily represent an obstacle to the introduction of CAD, when scanning systems that can read the designs of those who are not willing to abandon their traditional methods are used. Once the shapes have been scanned and stored in the computer, a system (such as PDS) can develop automatic size grading.

This family of CAD systems allows substantial productivity gains. It usually takes hours to manually modify and revise styles, whereas this task can easily be performed in few minutes, by means of computers.

3.2 Computers in the clothing industry: pre-assembly phases: b) cutting

Cutting is a very important phase in clothing manufacturing. The quality of a finished product depends on a proper execution of cutting. Personnel working in this phase are considered highly skilled for clothing industry standards. Accordingly, many big firms of this sector - widely relying upon subcontractors in the assembly stages - still prefer to perform cutting by their own.

The use of computers in the cutting phase is another source of significant gains both in productivity and in the quality of the finished good. The integration between CAD systems and computer-numerical control (CNC) cutting is crucial, in order to realize greater gains than those achievable when using stand-alone systems. Clothing already benefits from this integration in the late 70s, and this proved to be one of the first successful uses of CAD/CAM even in comparison with other manufacturing sectors (Hoffman 1989).

A computer guided system executes a cutting planning, based on a number of parameters of the fabric (colours, length) and the cutting room (number and length of cutting tables). As a result, the best combination of sizes and colours to cut together is realized. An accurate control of fabric length is made before the beginning of actual cutting, because a redefinition of cutting markers has to be made, if the fabric is found to be of a different length, from that used for the first markers. Where needed, changes can be introduced in a few seconds. However, the computer aided systems in cutting present a shortcoming, inasmuch as they assume that the fabric to be cut is fully free of faults, which is frequently all but true. One solution is an error-detecting system which localizes them on the fabric and can also calculate a new cutting plan.

These improvements are important considering that material cost is the largest component total cost (from 40% to 60%) in clothing. Consequently, even a few percentage points of material savings can imply a substantial cost reduction, depending on the value of the processed materials.

Moreover, automated cutting reduces skilled labour requirements (in a proportion ranging between 25% and 60%), while quality levels can increase due to higher precision and production rate can increase by a factor of around 3 (Hoffman 1989). A continuous production flow can also be conceived in clothing, by programming cutting system so as to work overnight (Disher 1991).

It is rather complex to have an idea of the diffusion rate of microelectronic-embodying systems. Nevertheless, a number of recent studies provide evidence for diffusion rates in various countries. Before examining these diffusion rates, it is worth stressing that the cost of these systems is still very high, roughly ranging from 100,000 dollars for a single module to as high as 10 million dollars for a integrated CAD/cutter (Hoffman 1989).

According to Hoffman (1985a), in 1982, around 700 CAD systems and 300 cutters were sold worldwide by American, French and Japanese firms. Besides, at the end of the 80s, more than 50% of all the US clothing production was reportedly made by means of CAD and CNC cutters, while in the UK more than 65% of the firms surveyed in a diffusion study in 1988 were users of CAD and/or of CNC cutters (Hoffman 1989). However, the former figure uses a measure of the *intra-industry* diffusion rate (i.e. CAD/CNC weight on *final garment production* in the US), while the latter figure is an evaluation of the *inter-firm* diffusion rate (i.e. how many *potential adopters* included in the sample of the surveyed UK firms actually introduced CAD/CNC systems). Both of them can be accepted, depending on the specific aspect of the diffusion rate that one wants to emphasize. As an example, when a high investment threshold represents one of the potential adoption obstacles, it is more appropriate to look at inter-firm diffusion rate. Intra-industry diffusion rate does not take market structure into account and can consequently overestimate the number of adopters. In this case, it is likely that adoption in the US is limited to a relatively small number of big companies, whose share on the final production is very high, while substantial obstacles still exist for smaller producers, with lower levels of investment per worker (estimated by MIT Commission (1987) in around 1,500 dollars per year).

Another recent survey on embodied technical change in supplier dominated firms (Santarelli and Sterlacchini 1993) focuses on the analysis of actual investment decisions[21] of a sample of firms working in footwear, clothing and furniture industries in the Marche region of Italy, where traditional sectors are well represented. It shows that during the 80s the adoption of various types of computer-based innovations (CAD, CAM, CAE, CIM, LAN) has been relatively high in the clothing sector, accounting for 16 out of a total sample of 18 systems in a survey of investments in computer-based innovations. The authors, in agreement with

[21] The database consist of detailed data on 88 investments by firms which during the 80s received long-term loans form an Italian financial institution (Mediocredito), operating on a regional level to support investment decisions of local firms. Mediocredito asked for detailed descriptions of the machinery or equipment or systems whose purchase has to be financed, thus collecting valuable data for scholars of innovation adoption.

Humbert (1988), suggest that the clothing sector is becoming a "knowledge-intensive industry", due to the growing trend of CAD adoptions.

The impact of the diffusion rate in the US is remarkable: the US government estimates that more than a half of the 3% per year growth in productivity in clothing recorded during the 80s is ascribed to automation in pre-assembly stages (Hoffman 1989).

3.3 Computers in the clothing industry: assembly phases

The assembly stage is the most difficult to automate and is consequently the less advanced of the whole textile-clothing *filière*. The main reason for this is that, when processed, any garment changes its shape, from two to three dimensions, thus tremendously complicating the conception of appropriate programs for full robotization. It is only with the advent of microelectronics that extending automation up to the clothing assembly stage becomes a realistic strategic task for the main industrialized countries. Still, even in the presence of a superior technology, like microelectronics, an enormous research effort is needed, often well above the means of the industry. This explains why, when considering innovative attempts in clothing assembly, one is straightforwardly led to examine public-sector supported research activities.

The task presents huge difficulties. In 1983, a study carried out at the UK Shirley Institute and Salford University Industrial Centre concluded that robots can undertake no more than 2 per cent of the operations studied (Tyler 1989). The share could rise up to 37 per cent of operations with significant further effort in development sensors, grippers and adaptive control techniques. Still the 37 per cent of all feasible operations covered only two-dimensional sewing, whereas the remaining three-dimensional operations (63% of the total) were rated beyond the capabilities of the robot technology. Courtaulds Clothing, working on a BRITE project focused only on two dimensional automation, reached a higher feasible share of around 60%. It seems that only Japan - in the context of the Automated Sewing System program (see infra) - is still aiming at a 100 per cent sewing automation, as shown during several machinery exhibitions in the 80s (Figure 11).

The last decade has witnessed a clear commitment from the industrialized countries to face and possibly to solve the puzzle of sewing automation. By the beginning of the 80s, cooperative research programs involving the main clothing companies, systems suppliers,

trade unions (in the US case) and governments were set up in the industrialized world. In the US the program was labelled as Textile-Clothing Technology Corporation (or TC2) and in Japan Automated Sewing System (or ASS). In the EC the program was part of the BRITE project. Sweden developed its own project as well. Though similar in their ultimate scope, the implementation of the various programs significantly differed among various countries.
TC2 was initiated in 1979 and received 3.5 million dollars per year from the US government from 1981 to 1988, while industry and unions provided another 5 million dollars per year. The involvement of the union in such a labour-substituting project is peculiar to the US case, where there has been a record of good working relationships among unions and manufacturers. Indeed, the union shared the view that restoring American competitiveness demanded cutting costs. The first target was to develop methods for automating sleeve assembly, a complex and highly labour-intensive phase. As usual in these ventures, time is a crucial variable, especially in order to be able to rise extra-funds for further research. In 1985 the Charles Stark Draper Laboratories (MIT - Boston) produced the first modular prototype allowing automated assembly of sleeves, coat backs and trousers. The system consists of several integrated units: an automatic loader to insert parts to be assembled into the transfer line; an automated vision system that recognizes the parts; a robot that folds and aligns edges; a transfer door that slides the parts to the sewing station; a sewing unit with feed belts and a sewing machine under complete automatic control (see fig.12). The main achievement at this point is the *integration* of computer-aided vision system with the control of the manipulator. At the same time, the system does *not* tackle the challenging task of three dimensional sewing. The TC2 strategy seems fully focused on the development of *dedicated machinery* for longer production runs. Interestingly, an equipment supplier is only involved in the project in the commercialization of the prototype. This is the well-known Singer Sewing Machine Company, whose core business is now in robotics and aerospace.
The ASS, started in 1983, received far more funding than TC2. It was funded by a joint government-industry support of 100 million dollars and it was supposed to last 7 to 10 years. MITI took part to the project, involving also 28 firms and 3 research institutions and oriented it from the outset towards a long-term perspective. The target was to realize a fully automated assembly, from design, through cutting, sewing, pressing and finishing to retailing. Contrary to the US experience, equipment manufacturers were key players from the outset of the

project, which militated in favour of a clear market orientation for the whole work. As already mentioned, the distinctive feature of the ASS is its declared commitment to what is currently considered the most difficult objective: full *three dimensional sewing*. The ASS approach aims to improve the *entire* clothing process. As a consequence, manufacturing time is expected to fall by at least a 50%.

As an example of potential final results of this research, Figure 11 shows a sleeve insertion workstation, including a movable head working on a garment dressed on a dummy, presented at Cologne in 1985. The most ambitious ultimate purpose of the project was to devise a system allowing even retailers to command from their shops digitally controlled machines to tailor *truly just-in-time* garments, based on holograms of the client's body (Hoffman 1989). No matter how futuristic the results, what really matters is that Japan is currently devoting its efforts to transfer the expertise gained in Flexible Manufacturing Systems (FMS) to the totally new field of clothing assembly. There is a clear intent to be the first in the world to develop these systems, thus becoming leaders in the world-wide supply of fully automated sewing systems. This could be a new niche of flexible automation market. The EC approach offers a much more scattered picture and deeply diverges from both TC2 and ASS. In fact, funds are not concentrated on a single big research program, but, in the BRITE scheme, several research projects covering many different aspects of the textile-clothing process have been 50 per cent supported by Community funds since the mid 80s.

In 1986, under BRITE Phase I, R&D clothing projects received 40 million ECU, or around 38 million dollars over a 5-year period (Disher 1986).

3.4 Innovative activity in clothing: analysis of EPO patent applications

The analysis of the patent applications at EPO gives further information on the innovative activity in clothing. A total number of 15 applicant countries can be found between 1980 and 1991, with Japan covering the leading share (38%), followed by Germany (18%), France and the US (11% each) (see table 7). Patent applications in this period picked in mid 80s, with more than a half of total applications between 1984 and 1987. It is worth noting that countries showing intense innovative activity in textile machinery -like Italy and Switzerland - are performing rather poorly in this technological class. Moreover, it is interesting finding

Taiwan as the leading applicant in 1989.

TABLE 6 EC BRITE CONTRACTS FOR CLOTHING INDUSTRY
(Projects running in 1990/91)

Project	*Countries*
Modelling of 3D flexible material surfaces to aid design	F/I
Prototype of a module of CIM in clothing industry	D/GR/NL
Flexible production groups in clothing industry	DK/I
CIM of synthetic filament yarn	F/UK/D
Optimization of worsted spinning for CIM development	F/B
Research on carded yarn process using new spinning techniques	D/E/F
Material transport devices for sequential automation	D/DK
Integrated system optimizing flexibility in textile-apparel	D/I/P
Flexible unit for removing textile workpieces from a pile	UK/E/F
Controlling processes for continuous textile finishing	D/E/B
Flexible sewing cell	E/NL/I
Flexible assembly cells for automatic clothing processing	D/DK
Sewing machine oriented to seams under electronic control	F/I
Detection evaluation mapping of defects on finished fabrics	I/D/UK
Development of a system to detect and to mark defects	B/NL/DK/P
Modular device for automatic recognition of defects	P/F/B
Multisensor visual inspection in high speed garment prod.	E/I/F
Quick Quality Response	DK/F/D
Research into the fundamental parameters of dyeing	B/UK/D
Optimization of acrylic fibre surface for yarn spinning	UK/I/E
Unmanned knitting plants	IRL/B/NL/I
Mathematical and rule based optimization of cotton blends	B/D/F
Automatic handling techniques for non-rigid materials	UK/I/GR
Artificial leather processing for environment safeguard	I/P/NL/IRL

Source: EC Commission

TABLE 7 PATENT APPLICATIONS AT EPO: METHODS FOR MAKING CLOTHES (technological class A 41 H)

	80	81	82	83	84	85	86	87	88	89	90	91	Total
FR	1	0	1	1	3	2	2	5	0	3	1	1	20
IT	0	1	0	0	1	0	1	0	1	1	0	1	6
DE	1	0	3	1	2	3	5	4	7	4	1	1	32
GB	0	0	0	0	0	0	3	1	1	2	0	0	7
JP	0	3	4	3	14	3	15	10	3	4	8	0	67
US	0	0	1	1	3	3	2	1	1	2	1	4	19
TW	0	0	0	0	0	0	0	0	0	6	0	0	6
SE	1	1	0	1	0	1	0	0	1	0	0	0	5
CH	0	1	1	0	1	0	0	0	0	1	0	0	4
ES	1	0	0	0	0	0	2	1	0	0	0	0	4
Other	0	1	1	0	0	0	1	1	1	0	0	0	5
TOTAL (stock)	4	11	22	29	53	65	96	119	134	157	168	175	
TOTAL (flow)	4	7	11	7	24	12	31	23	15	23	11	7	175

Legend: FR=France; IT=Italy; DE=Germany; GB=Great Britain; JP=Japan; US=United States; TW=Taiwan; SE=Sweden; CH=Switzerland; ES=Spain
Source: Cespri-Bocconi EPO Database

3.5 Microelctronics and telematics linking textiles and clothing: the advent of quick response programs

The new opportunities opened up by the use of microelectronics also concern the adoption of entirely new production philosophies, such as *quick response* (QR) programs. These are the equivalent for the textile-clothing complex of just-in-time programs in the automobile industry. QR attempts to answer effectively and in time to whatever need is coming from the market. Communication flows are crucial in this scheme, as they are supposed to rapidly link together the various levels of the textile-clothing-retailing *filière* as a whole (see Figure 13). These connections are devised in order to quickly respond with high quality products to emerging demands, from the final retail level. The various components of the textile-clothing-retailing complex interact as if they belonged to a single unit.

The three main elements of a QR scheme are: flexible technology, information systems and organizational changes (Derichs and Fisher 1992).

As far as flexible technology is concerned, QR requires *quick change*. This is not the type of paradigm followed by technical progress for textile machinery, as described above, where performance parameters such as speed have changed dramatically in the last decades through a single unit executing its job on a sequential step-by-step basis without any interruption of the steps. However, the machinery, though innovative, is more suitable for mass production, whereas what is needed nowadays is the possibility of rapid change and small-batch processing. New solutions on this ground already exist: as an example, in weaving, new warp change systems point to the right direction, significantly reducing the setting-up times.

In addition, for QR schemes to properly work, an information system is needed. A full implementation of the system requires two main tools: bar coding, for data entry at all transaction points, and Electronic Data Interchange (EDI), which allows the exchange of structured trade data between computer systems of trading partners. EDI, in turn, requires four key elements: i) electronic mail, assuring rapid interpersonal communication; ii) on-line networks; iii) electronically-based business documentation; iv) standard protocols for file transfers. Nowadays, it seems that further work is needed for a proper formulation of messages concerning all the relevant information (not only purchase orders and invoices but also production data) which can be exchanged between textile, clothing and retailing. The crucial step on this ground will be the emergence of a *standard* for the documents to be sent via EDI, which must comply with the UN international EDIFACT standard. At the EC level, the definition of the EDITEX standard - explicitly dedicated to textile-clothing industry and included into the EDIFACT scheme - is currently under scrutiny. As a result of EDI use in QR schemes increased sales, reduced stocks and improved profits can be obtained.

There is evidence for the diffusion of these systems in the US. As an example, TC2, in its effort to build a reputation in QR, set up a partnership with Dillard's and Milliken, the latter being one of the first US users of EDI (Textile World 1987). Point-of-sale information from Dillard's - via EDI - allows Milliken to supply fabric following a just-in-time scheme (Abend 1992). Milliken adopted QR systems based on EDI during the 80s: the turnaround time was correspondingly cut from 6 weeks to one (Forger 1989). The same trend is being followed by another major US producer, Levi Strauss & Co.: the position of 'director of QR' has been created and information with retailers and suppliers are exchanged through EDI (Brousell 1992). As a result, leadtime for new orders is now 7 to 10 days. More interestingly, there is evidence for the expansion of EDI boundaries towards the production sphere: a network services supplier - such as GE Information Services' Design Express - allows apparel companies to transmit design patterns and related information to manufacturers worldwide (Guisbond 1990). In Europe, Marks & Spencer reportedly launched a 250 million pound investment program in the mid 80s for electronic ordering and invoicing (Ogilvie 1991). Among the main European manufacturers, Benetton Group heavily relies upon EDI to link its independent agents in as many as 73 countries (Rullani and Zanfei 1988; Ramsower 1991). Other highly internationalized Italian textile-clothing groups - namely Gruppo Tessile Miroglio (GTM) and Gruppo Finanziario Tessile (GFT) - are early adopters of telematic systems (Rullani and Zanfei 1988).

The difficulties involved in realizing the project of an information network between users and suppliers in the textile-clothing sector are not only confined to the strictly technological ground. A potential *cultural* obstacle should not be underrated. It can be of some interest to recall the experience of the telematic project for Prato (Florence) - one of the most important Italian wool districts (Bellandi and Trigilia 1991). As early as the mid 80s, ENEA (a public agency also working in technological diffusion) in cooperation with local administration and Industry and Artisan Associations promoted a telematic network among local firms, in order to distribute on-line information about subcontracting demand and supply. However, the implementation of the project has been very difficult in the highly competitive context of the Prato district, due to the concern of firms about the undesired spread of important information on inter-firm transactions (considered as *intangible assets*).

4. CONCLUSIONS

The analysis carried out in the previous chapters of this work allows to draw a number of broad conclusions concerning the technological development of the textiles and clothing sector in the last decades.

4.1 Textiles and clothing: a mature or "knowledge intensive" sector?

The record of technological upgrading in this sector induces to reconsider the assumption of maturity of the sector (Mody *et al.* 1992). An alternative picture can be drawn by focusing on some recent developments.

Firstly, is misleading to label as mature a sector[22] showing during the 70s and the 80s a productivity growth rate far above that of manufacturing as a whole in several industrialized countries (MIT Commission 1987; Hartmann 1985; Heimler and Milana 1984; Milana 1987). This positive productivity record is a result of the wide and complex evolutionary process in textiles and clothing. In fact, this has led to several changes in the sector:

i) the structure of the industry shows an increasing trend towards higher degrees of *concentration*, both in textiles and in clothing (Hoffman 1985a). This allows to overcome one of the main obstacles to the deployment of innovative strategies in the sector, namely a limited base in terms of financial resources and, more widely, know-how;

ii) though usually known as the labour-intensive tail of manufacturing, the sector is clearly moving towards an higher degree of *capital intensity* (especially in textile). The development currently taking place in clothing is even more interesting, with a potential rise in a *knowledge-intensive* and highly value-added segment of the sector;

iii) the strategies of the main groups are being rapidly adjusted to the fast-changing competitive scenario in the textile-clothing market. Key success factors during the last ten years have been the strong reliance upon *product diversification*, in order to face final demand turbulence, coupled with the adoption of a complex sub-contract sourcing on a worldwide scale, in order to reap the most favourable conditions from suppliers. Yet it is worth noting that it is hard to point to one clearly dominant strategy, because many different alternatives coexist, such as high vertical integration at home and export; subcontracting (both at a

[22] It is worth mentioning that what follows mostly applies for textiles and - only to a limited extent - to clothing.

national and at an international level); foreign direct investments;

iv) competitive tools are consistently changing, as well. Cheap labour is progressively losing its status as the key variable to achieve success on the international market. A high profile human capital and a good infrastructural base are already playing a crucial role even in the supposedly mature textile-clothing sector. In fact, they are considered indispensable for innovative strategies aimed at taking full advantage from the new opportunities offered by the availability of well-trained employees, superior product design and the continuous development of new processes;

v) new technologies in use in textile-clothing represent another crucial source of important changes. However, even more important than the technological improvements *per se*, one should also consider the growing attention paid by firms to new machinery and new microelectronic-based production systems. It is no longer possible to stay competitive without heavily relying upon new technologies in order to realize essential productivity and quality gains;

vi) new, mostly technology-driven, *organizational* structures have been adopted by textile-clothing firms, to fully benefit from *inter-sphere* automation (Kaplinski 1985). This is shown by the increasing evidence of intra-firm or intra-group reorganization due to the rise of new production modes, such as quick response schemes, which are by now widely adopted by the main US producers (like Milliken and Levi Strauss) and/or retailers. *Inter-firm* relationships are subject to an intense evolutionary process, too. In fact, an *inducement effect* produced by the behaviour of bigger groups drives different actors working at various stages of the textile-clothing *filière* into highly flexible production schemes.

4.2 Innovation diffusion in textiles and clothing: main obstacles

The aforementioned dramatic changes in the textile-clothing complex do not fully rule out the existence of significant obstacles to innovation diffusion, which can be ascribed both to some specific characters of the sector and to the nature of the technologies.

Indeed, as shown in chapter 2, the dominant techniques in world installed textile productive capacity are still the relatively older ones, namely ring spinning and shuttle looms, even though the diffusion of their competing technologies began as early as the 60s.

In clothing, it is only with the recent arrival of microelectronics that truly innovative techniques were available and, for the reason given below, *inter-firm* diffusion rates are still low, though the *intra-industry* diffusion rate of microelectronic-based systems has significantly grown in the last ten years (see section 3.2). In other words, it is likely that bigger companies, covering a high share of final production, have widely adopted innovative systems, embodying microelectronics, whereas smaller firms are still lagging behind.

A number of obstacles slow diffusion rate in textiles and clothing.

Firstly, the sector has historically shown a rather conservative risk-adverse attitude, which is not surprising in one of the *oldest* production sectors and is presumably still widespread among the myriad of the small and marginal producers. They usually lack the financial resources and know-how to undertake increasingly complex innovative efforts. An example is the history of the shuttle-less invention (see section 2.3).

Secondly, *radical* changes involved by the introduction of process innovations can significantly retard the adoption of new technologies or new systems. In this respect the current patterns in textiles and clothing diverge. For instance, technological development in textiles evolves along traditional lines where the basic organisation of the manufacturing process has not changed, though several parameters such as speed have been dramatically improved (OECD 1988). Conversely, progress in clothing has instead taken place by renewing entire "blocks" of operations, whose actual execution has been modified by microelectronics, as in the case of CAD linked to CNC cutting systems.

Moreover, the *timing* of appearance of innovation should not be underestimated. In textiles, as described in chapter 2, a *continuous flow* of consecutive improvements in machinery characterizes the technological development, since the 50s. Innovations in clothing in contrast are *revolutionary* in their nature and point from the outset towards a rather different path, involving the modification of well-established routines. As an example, new microelectronic-based systems are increasingly shifting the comparative advantages of firms from *skills*, defined as "a set of practiced experience" and as such crucial in clothing so far, towards *knowledge* - or "information at an abstract level" (Kaplinski 1985).

Thirdly, the size of the required investment in new technology can reduce the number of potential adopters. Moreover, the actual size of the investment is difficult to measure, because it frequently involves the recourse to *ad hoc* solutions, in the attempt to adapt new technologies to the needs of the firm. Thus, the low degree of standardization makes each *tailored* innovation more costly, while at the same time the relationship with specialized suppliers becomes crucial. Significant *sunk costs* can also be involved, when, as it is often the case in textile (see sections 2.2 and 2.3), the older technology remains competitive to a certain extent with the newer one. This usually happens when new machinery dramatically improves the overall performance on a *specific* characteristic - say, speed - while it scores comparatively badly as far as its *versatility* is concerned.

In addition, when comparing the investment cost with the size of the potential adopter, the more or less formal links of a firm with bigger *business groups* must be taken into account, given the current context of increasing degree of concentration in textiles and clothing. A recent study on the adoption of new technologies in supplier dominated sectors (Santarelli and Sterlacchini 1993) confirms this trend and interestingly concludes, based on regression analysis, that: "firms that are affiliated with a business group are characterized by higher average impact of embodied technological change", whereas the impact of the *mere* firm size on the adoption pattern of embodied technical change is not significant.

Finally, the adoption of microelectronic-based systems contrasts with well-established investment procedures in textiles and clothing, and presumably in other sectors as well. Indeed, a *systemic* approach - linking automation of design, manufacture and coordination spheres (Kaplinsky 1985) - gives a higher value to investment in microelectronics than a more traditional step-by-step procedure, which can lead to the creation of relatively unfruitful *islands of automation*. Many factors, such as financial constraints, militate against adopting a systemic approach. Even more importantly, time-consuming *learning* processes are involved in the adoption of automation and result in the often observed *sequential* path in the introduction of automation (Dosi and Moggi 1989).

4.3 The impact of microelctronics on textiles and clothing: the role of technology suppliers

In the pathbreaking article by Pavitt (1984) one finds an enlightening scheme of intersectoral technological relationships (p.364), which clearly shows that supplier dominated sectors take advantage of technical change produced elsewhere in the economy.

In the last decade, the profile of equipment suppliers to textiles and clothing started to change (Hoffman 1985a), with the entrance of firms mainly concerned with using information technology and extending the sphere of their interests to the application of microelectronic-based systems in textiles and clothing. In fact, when CAD software for clothing was established as a totally new market segment, the systems were first supplied by firms which used to work in different, highly innovative sectors - such as aeronautics. As an example, in the US, Hughes Apparel Systems, one of the first CAD systems suppliers to clothing industry, is a subsidiary of Hughes Aircraft, which was eventually taken over by a prominent American equipment supplier - Gerber Garment Technology.

The establishment of this group of suppliers appears to be a very important step. In fact, the record of textile-clothing technological development clearly shows that a crucial role in technological upgrading has been played by the formation of a sector supplying new machinery and equipments. In the electronic era, something similar has also happened, with the formation of a supply sector for innovative equipments embodying microelectronic systems. A non-conventional link between science-based and supplier dominated sectors, has gained growing relevance.

As shown by Hoffman (1985a), some of the most active developers of the first systems were small firms with electronic background, which successfully diversified their activity into a sector where they had no previous experience. However they could effectively compete with well-established textile-clothing equipment suppliers which were, in turn, lagging behind in microelectronics. The role of small, "Schumpeterian" firms - exploring new opportunities and developing new systems - in the setting-up phases of the supply of microelectronic-based systems has already been described as a stylized fact in the technological transition from electro-mechanical to electronic regimes (Dosi and Moggi 1989).

After the initial stage, a *competitive* group of larger world scale suppliers of microelectronic equipped systems, mainly for the clothing sector, seems by now working in the main industrialized countries (examples include: Gerber Garment Technology in the US; Juki in Japan; Lectra and Investronica in Europe).

The equipment supply sector is undergoing a crucial evolution, which could possibly transform it into a high-technology one (Hoffman 1985a).

If this trend is confirmed, it could pose a significant threat to all those producers who have mastered the previous electro-mechanical paradigm, but who still lack expertise in microelectronics. There is evidence for intense monitoring activity by traditional suppliers of recent technological developments, in order to upgrade their capabilities in microelectronics, relevance of the biggest distribution chains. The final market share covered by big retail chains and mail order services had grown in France from around 19% in 1977 to over 28% in 1984 (Mytelka 1987). More importantly, the kind of products that are sold by big retail chains are mostly of a low to medium quality, namely the type of products which are better suited to automated production processes. Furthermore, quick response schemes have made big retailers very sensitive to the best available technologies on the market. In fact, they have induced their suppliers to adopt mainly microelectronic-based innovations, which allow them to fulfill product variety at a lower cost, with a higher quality and more rapidly. As an example, this is the approach followed by Marks & Spencer in the UK, since the mid 80s (Disher 1987).

4.5 The impact of microelectronics on textiles and clothing: is there room for trade reversal?

The technological advancements already obtained and, more importantly, those which could be achieved in the future based on microelectronics, can significantly re-shape the international division of labour in textiles and clothing (Yamazawa 1983; Hoffman 1985a; Hoffman 1989; Mody *et al.* 1992). Indeed, there can be room for *trade reversal* if the diffusion of automated systems allows to significantly reduce the manufacturing cost, especially in the highly labour-intensive phases of clothing.

In this case, the competitive scenario of the sector could dramatically change, at least as far as specific product ranges are concerned. Design and even the engineering of the final product have become crucial aspects of the competitive advantage, whereas cheap labour is no longer sufficient to induce the international delocation of production. On the contrary, it is the geographic proximity with *final markets* that is growing in relevance.

The diffusion of microelectronics in the more labour-intensive sector of clothing has reinforced the hierarchy among world producers. Apart from the developed countries, which are obviously those who are better placed to reap the greatest benefits from the diffusion of computer-based systems, NICs can also substantially benefit. They are already able to master the use of CAD in pre-assembly phases, where complex techno-managerial capabilities are required to take advantage of the adoption of these systems (Hoffman 1985a). In addition, the NICs can significant gain from the diffusion of microelectronics in the assembly phase, given their fast-growing wage levels.

On the contrary, the incentives for the adoption of these systems in developing countries are rather poor. The lack of necessary knowledge seriously hinders the prospects for an effective use of computers in pre-assembly phases, correspondingly lowering their diffusion rate. Moreover, in clothing assembly very low wage levels still allow traditional techniques to compete in terms of manufacturing cost with the newer one.

While developed countries and NICs move towards the technological frontier for textiles and clothing, it is conceivable that the majority of low-wage countries will compete among themselves in a shrinking portion of the market.

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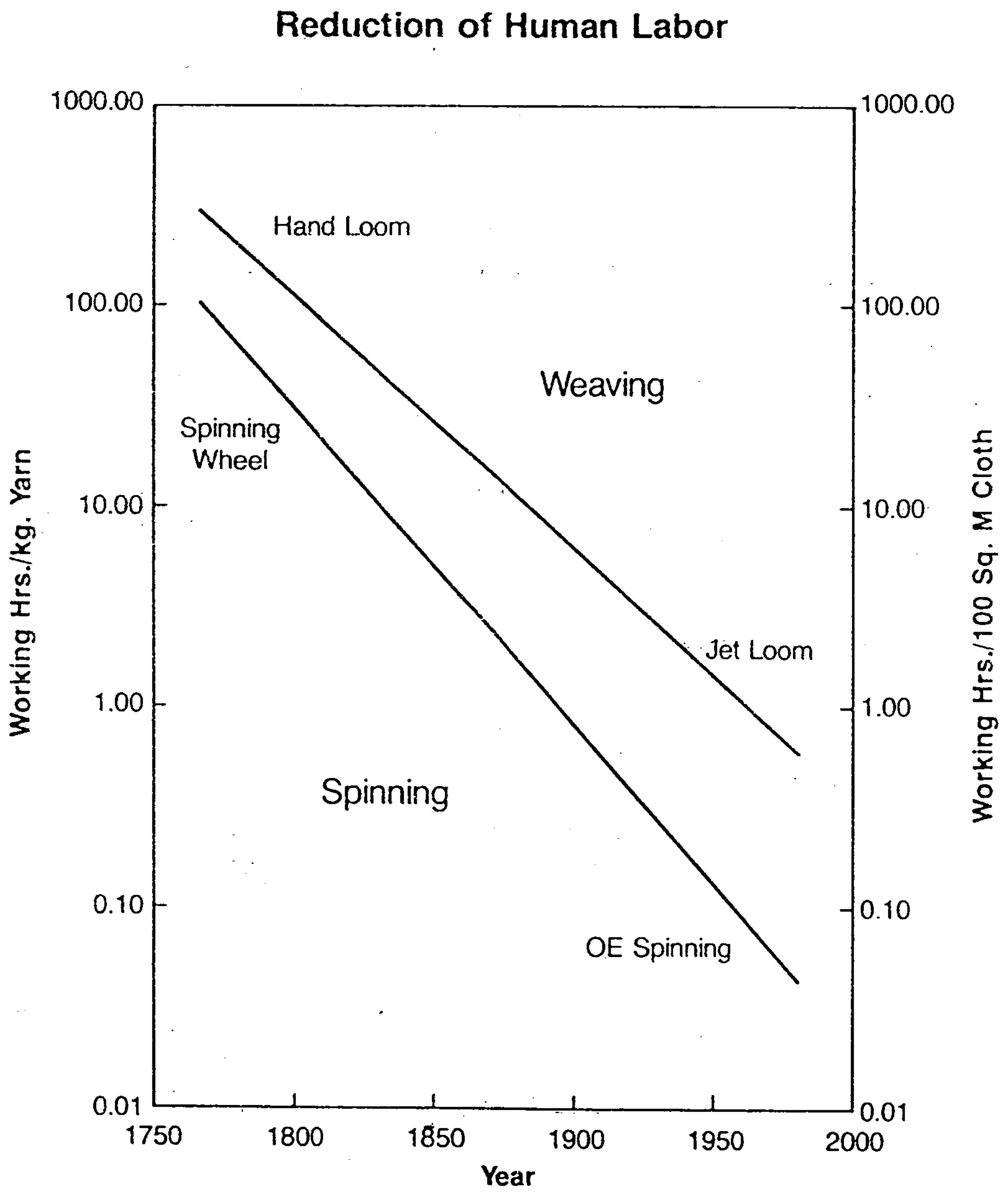
Annex: Figures

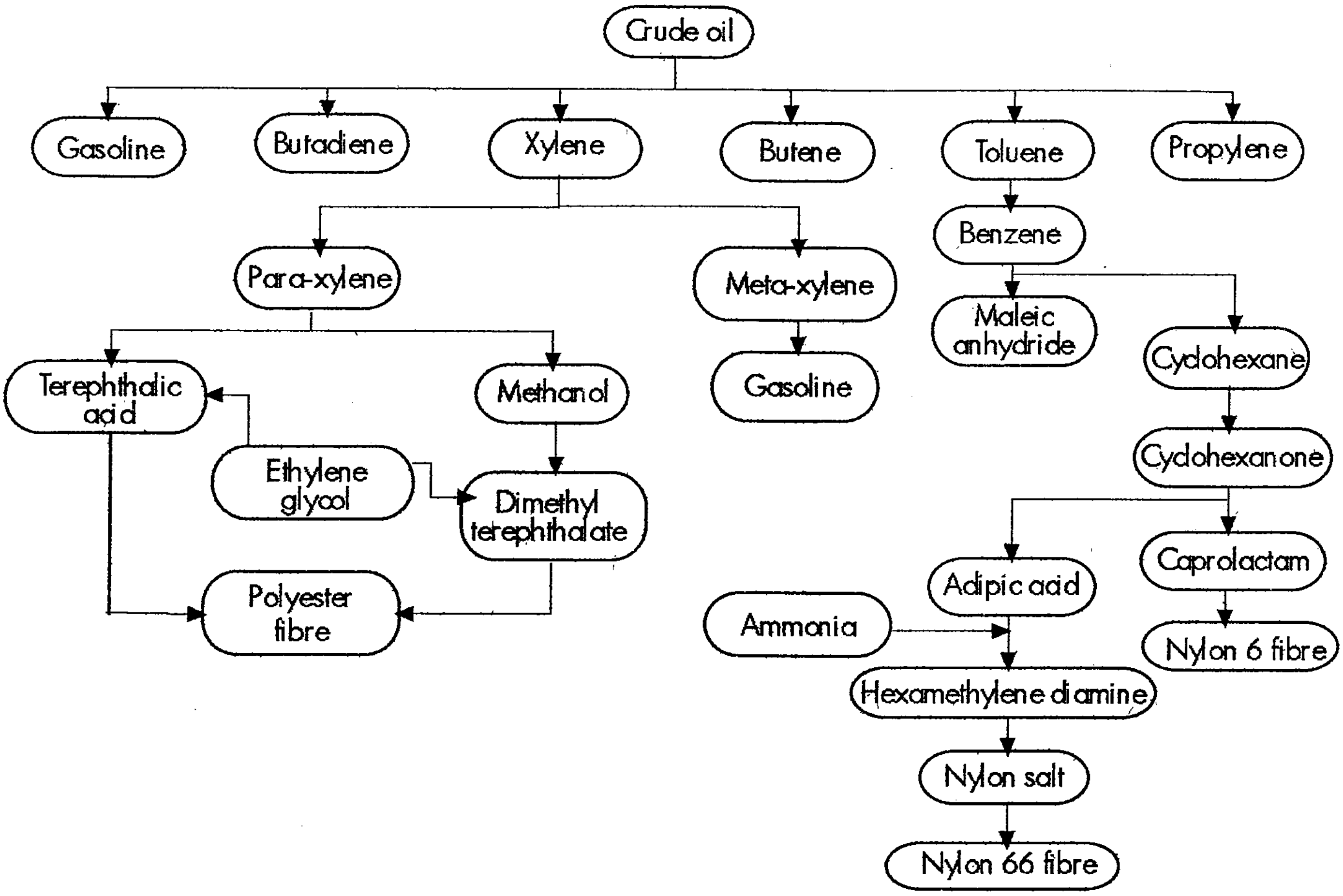
FIGURE 1



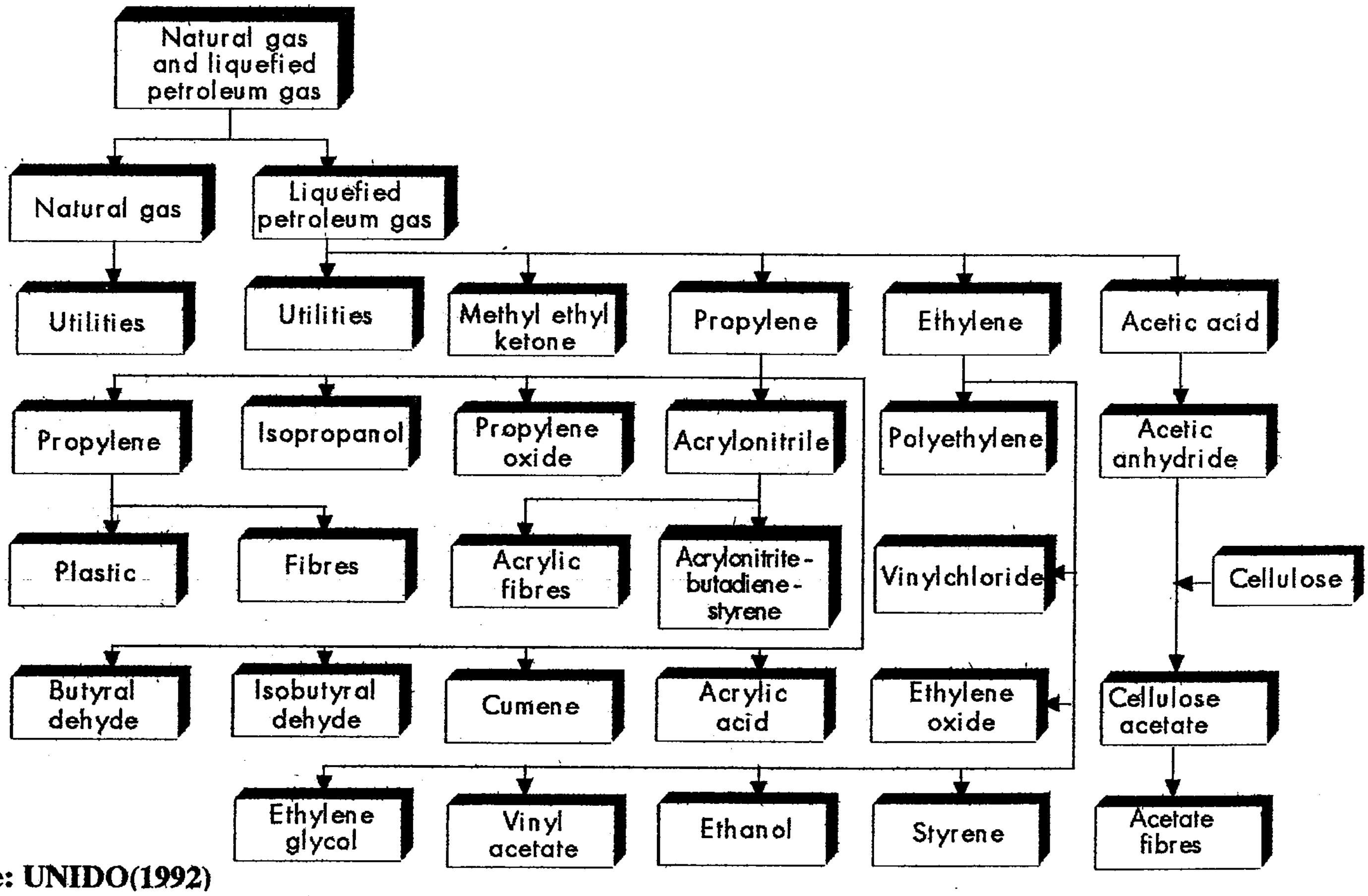
Source: Krol (1985)

FIGURE 2

A) Syntetic - fibre petrochemical flow chart

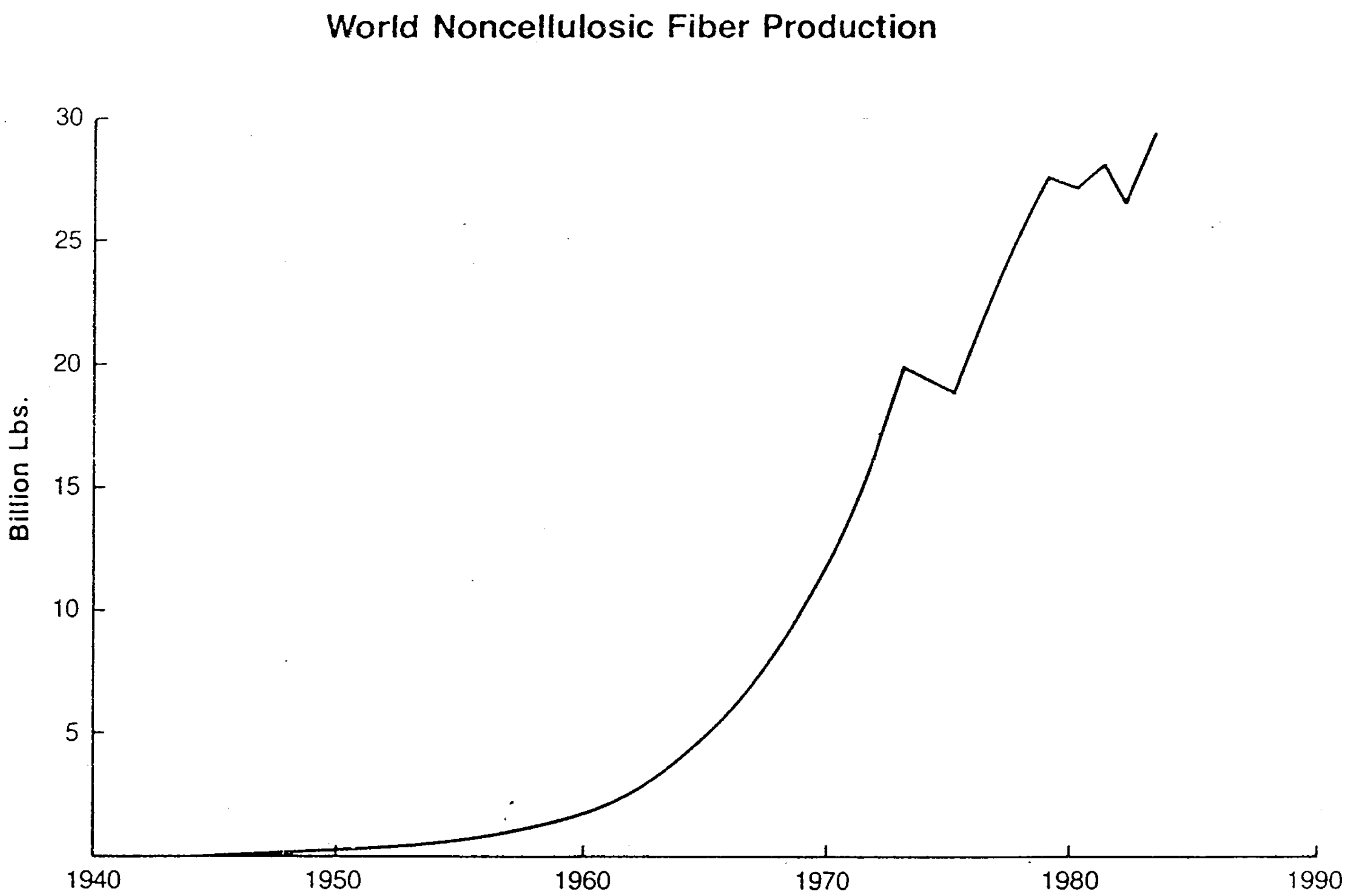


B) Syntetic - fibre petrochemical flow chart



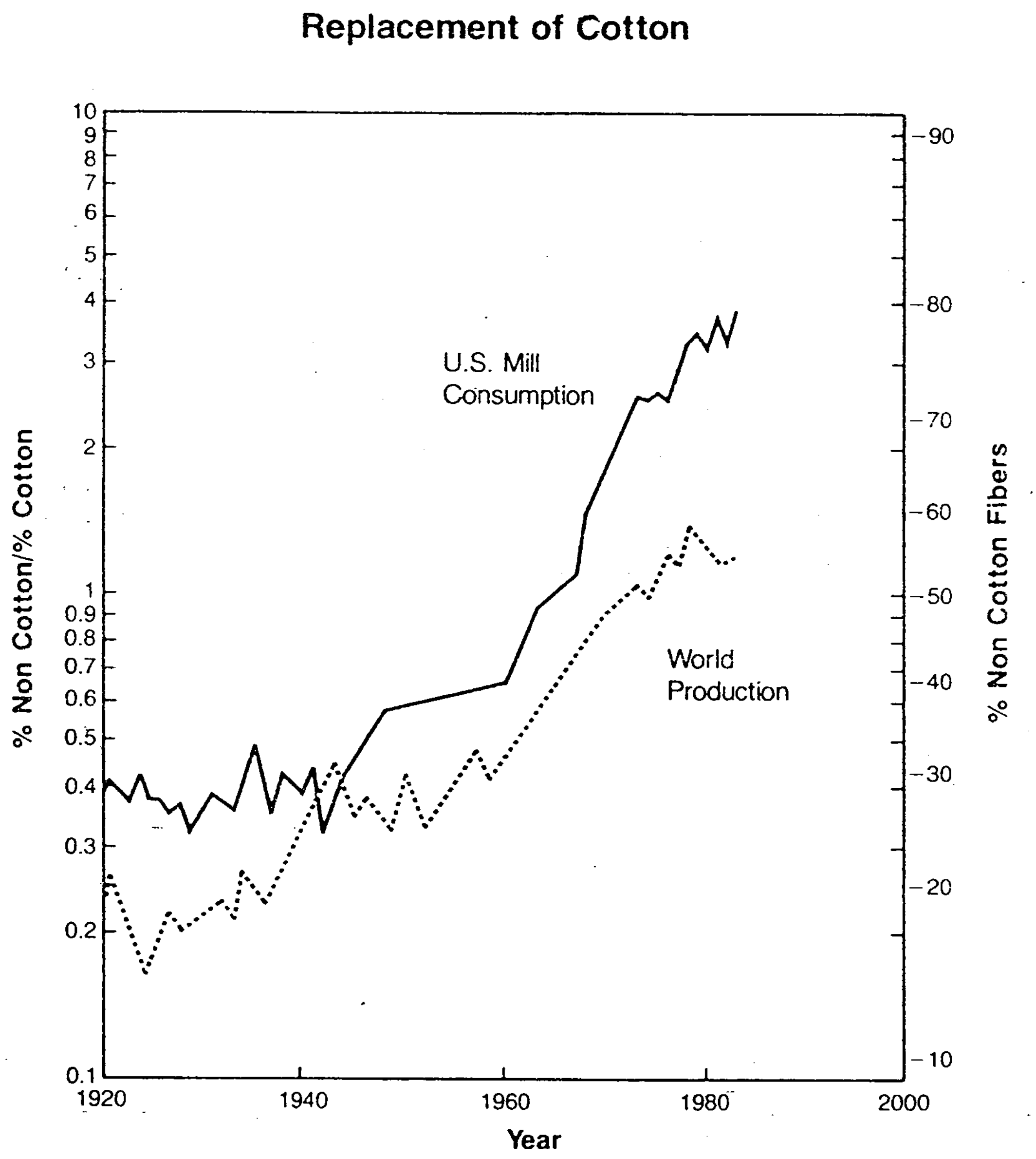
Source: UNIDO(1992)

FIGURE 3



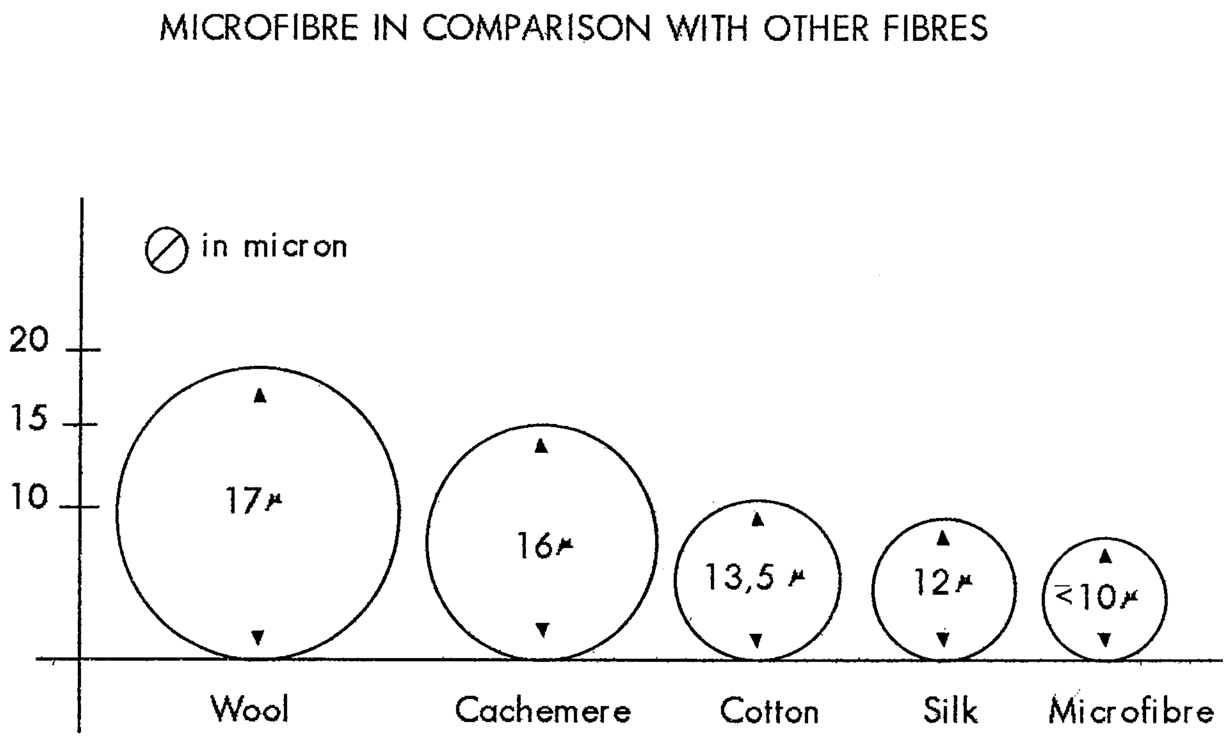
Source: Krol (1985)

FIGURE 4



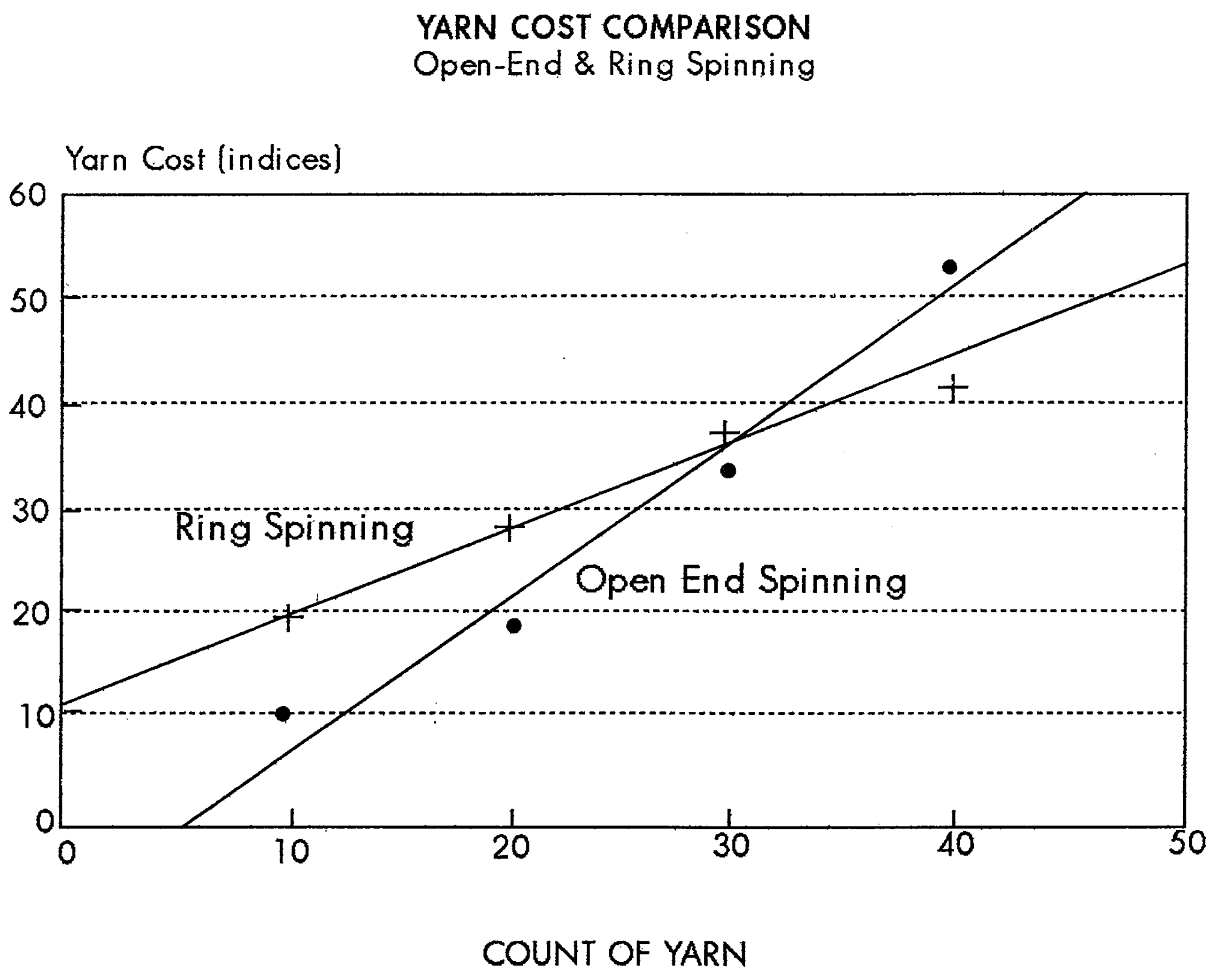
Source: Krol (1985)

FIGURE 5



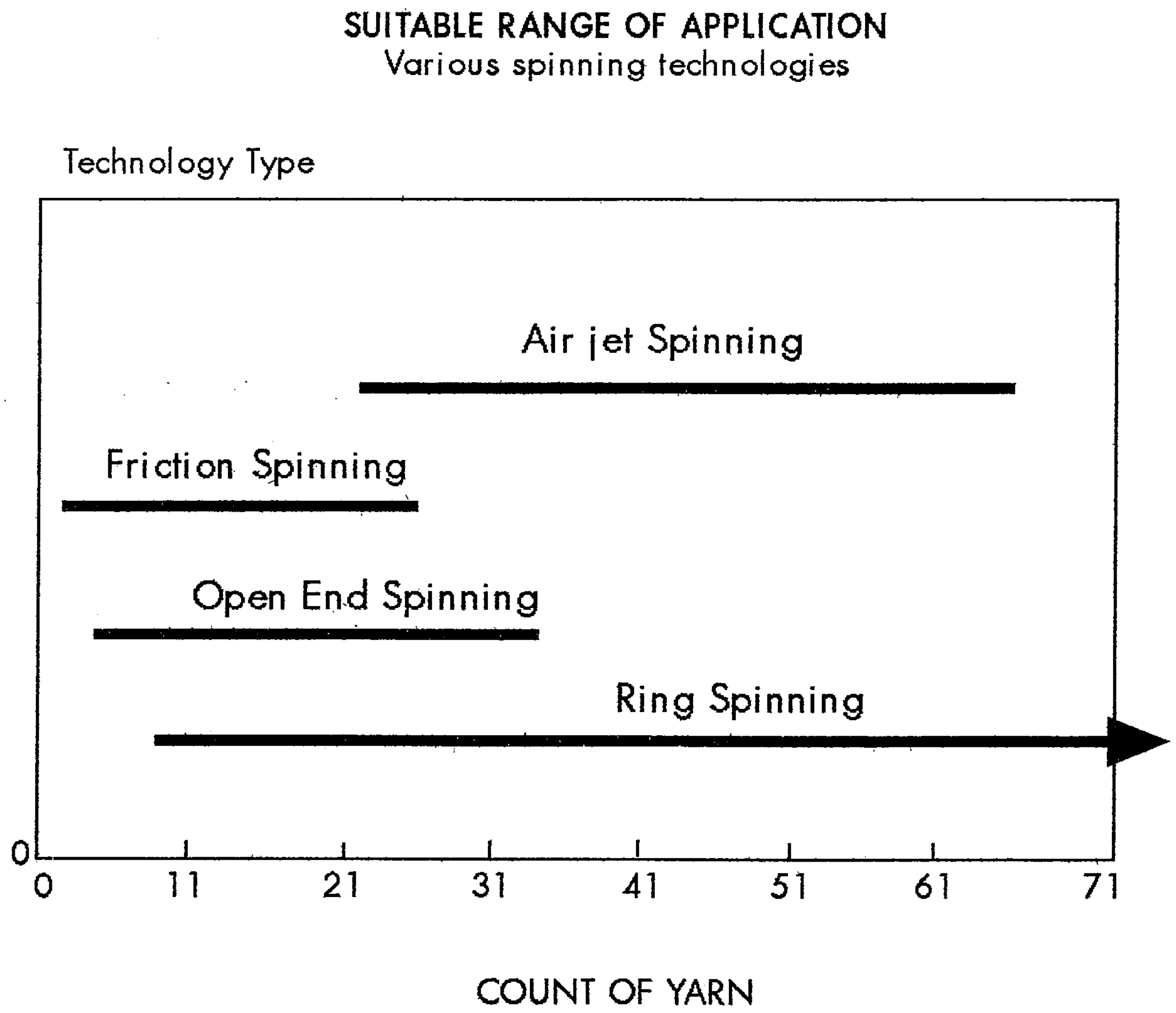
Source: Assofibre (1992)

FIGURE 6



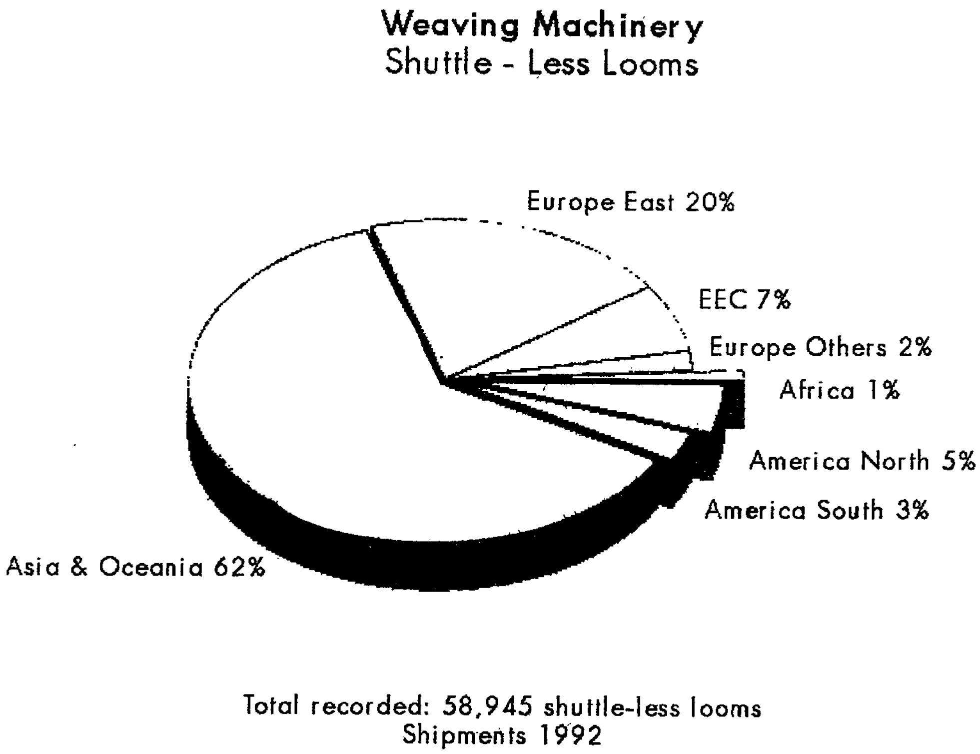
Source: Pepper Battacharya (1991)

FIGURE 7



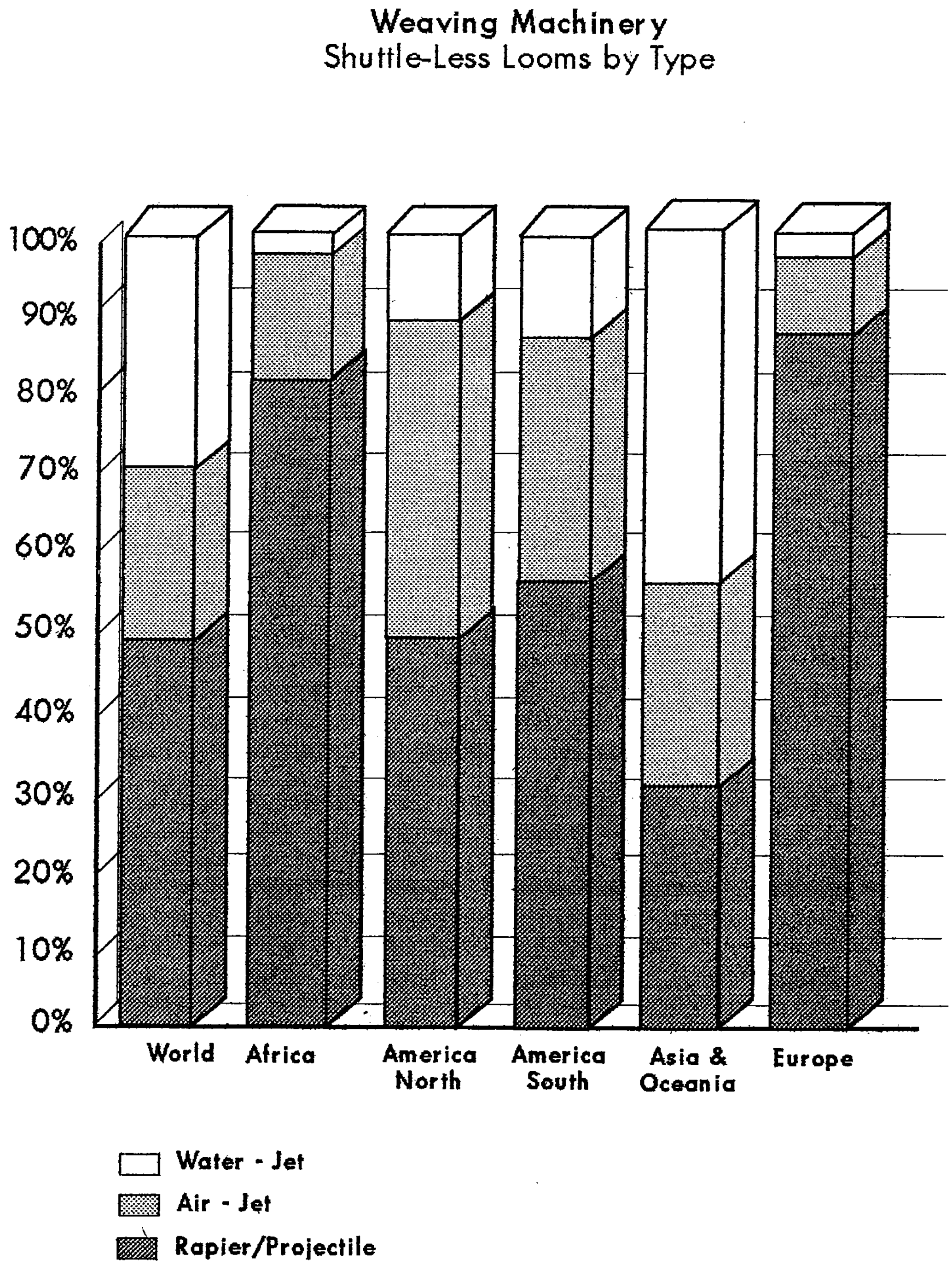
Source: Pepper Battacharya (1991)

FIGURE 8



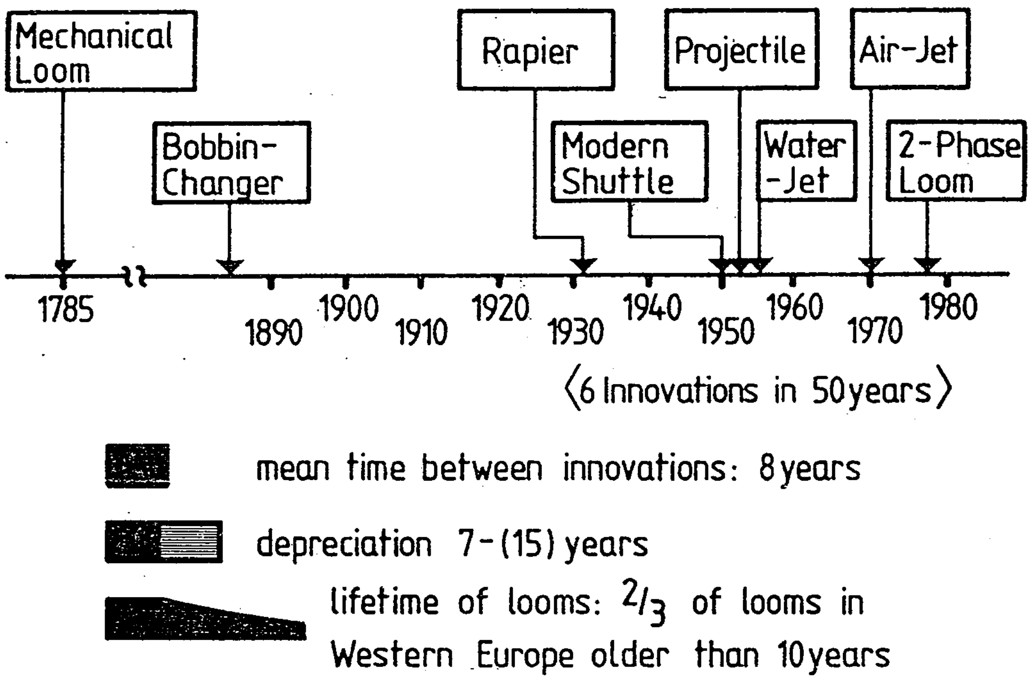
Source: ITMF (1993)

FIGURE 9



Source: ITMF (1993)

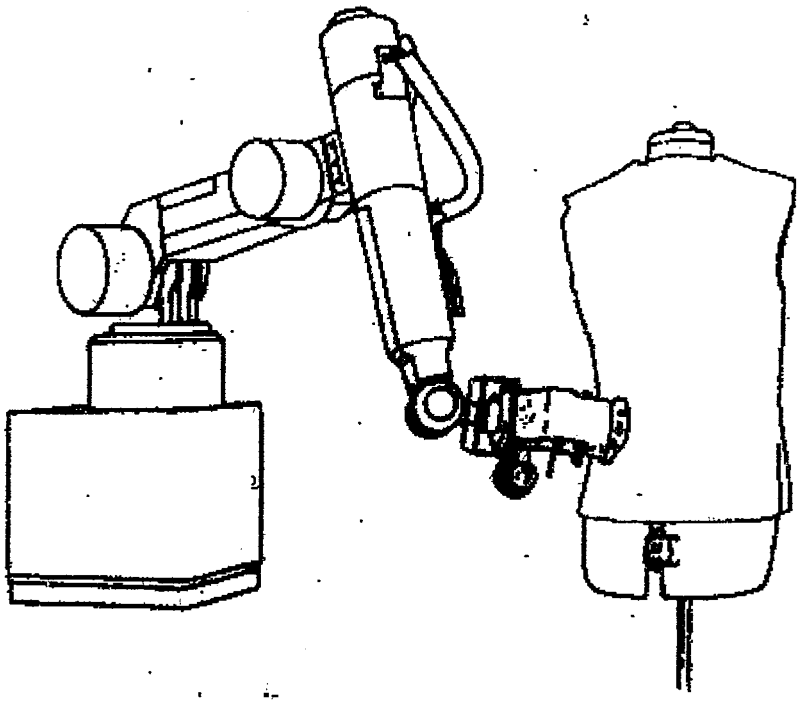
FIGURE 10



Source: Locher (1985)

FIGURE 11

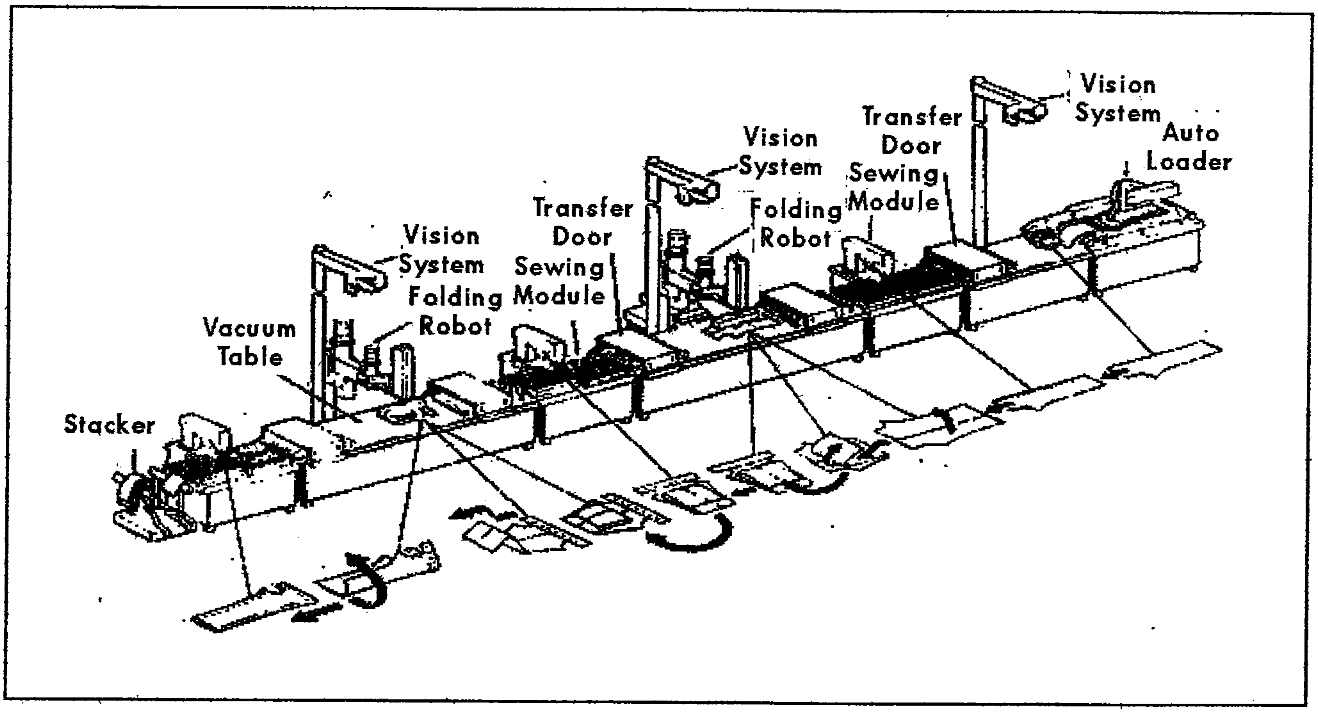
JUKI 3D STITCHING WORKSTATION



Source: Tyler 1989

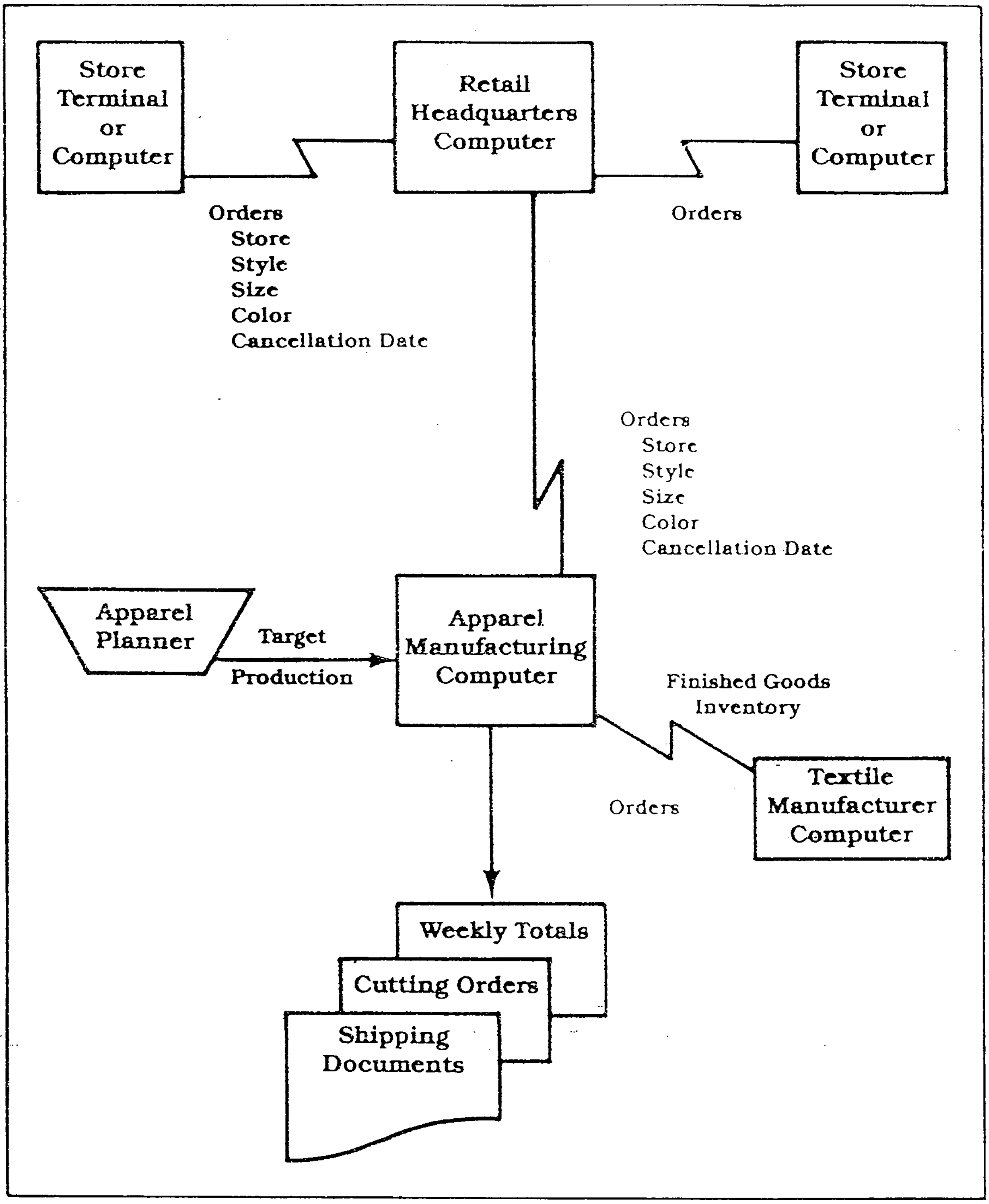
FIGURE 12

$(TC)^2$ TRANSFER LINE FOR TROUSERS PRODUCTION



Source: Disher (1986)

FIGURE 13
A QUICK RESPONSE SCHEME



Source: Textile World (1987)